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A STUDY OF RUNOFF AND WATER QUALITY ASSOCIATED WITH THE WILDLANDS OF THE PRICE RIVER BASIN, UTAH

FINAL REPORT

CONTRACT NO. YA553-CT1-1064

USDI BUREAU OF LAND MANAGEMENT

By

Unitex Corporation
4568 Highland Drive, Suite 240
Salt Lake City, Utah 84117

July 10, 1982

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Foreward

This report was prepared by UINTEX Corporation, 4568 Highland Drive, Suite 240, Salt Lake City, Utah 84117 under BLM Contract number YA-553-CT1-1064. This contract was initiated by Special Studies Division at Denver Federal Center with Gordon Bentley and William Jackson acting as Technical Project Officers. William Battle was the contract administrator for the Bureau of Land Management. This report is a summary of the work recently completed as a part of this contract during the period August to December 1981. This report was submitted by UINTEX in February, 1982.

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UINTEX wishes to thank Mr. George Cook of U.S. Soil Conservation Service in Price, Utah for his advice on the salinity properties of soils. Mr. Sal Palalay and Mr. Ray Price of SCS, in Salt Lake City, Utah provided soils data and their kindness is greatly appreciated.

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Summary

This report is organized in two parts; each part is self-contained and may be read independently:

Part I: Storm runoff and water quality in selected ephemeral streams of the Price River basin, Utah.

Part II: Baseflow runoff and water quality in selected streams of the Price River basin, Utah.

Tables of Contents are prepared separately for each part. Major findings of Part I and Part II are given as follows:

Conclusions/Part I

The following conclusions may be drawn from this study:

(1) The salt/solid ratios associated with storm runoffs are related to soluble mineral content of erodible soils.

Excluding the snowmelt runoff event, the mean TDS/TS ratios, runoff-weighted, are:

Wattis Watershed	: 3.43%
Soldier Creek	: 3.58%
Coal Creek	: 1.69%
Grassy Trail Creek	: 2.10%

For Mancos Shale areas, such as Wattis and Soldier Creek drainages, a 3.3% (or 1/30) may be a reasonable figure for the prediction of TDS from sediment load. For other less saline areas, one should expect a lower figure.

(2) The relative uniformity of average TDS/TS ratio suggests that TDS concentration is strongly dependent on sediment concentration. Except during active periods of solute pick-up from channel salt crusts, and during periods of low turbulence, the instantaneous value of TDS/TS is only slightly less than the soluble mineral content of the eroded soils.

(3) Overland flow processes are important factors in salt production from wildlands. However, channel solute pick-up could be of equal importance in some drainages for some storms, especially during runoff events preceded by long, dry periods. Little baseflows are observed for the storms monitored.

(4) Reasonable success with USLE appears to be a useful tool in estimating relative EC loadings from overland runoff. The underlying principles of the USLE are consistent with findings of this and other related studies.

(5) For a given storm runoff the overland and in-channel components of solute pick-up can be separated quantitatively, if

enough details of the hydrograph, the TDS- and the TS-graphs are collected.

(6) In-channel solute pick-up mainly occurs in the inital phase of the storm event. Instantaneous values of TDS/TS and TDS should be examined simultaneously to confirm the channel solute pick-up process.

(7) A scenario of in-channel solute pick-up is proposed: given enough time, salt encrustations should reach a mature state. The total quantity of soluble mineral of a matured encrustation for a drainage is more or less a constant. And this constant varies from drainage to drainage depending on how much Mancos Shale is exposed in the channel.

(8) Channel solute pick-up in Wattis watershed is estimated at a maximum of 8 tons for matured salt encrustation. This salt pick-up is about 20% to 40% of the observed salt load of a storm, but this percentage would vary as a function of storm size and sequencing. The corresponding estimates for Grassy Trail Creek and Coal Creek are 10 tons and zero respectively.

(9) Almost all the water samples analyzed for ion species show saturation with respect to calcite, for all the watersheds and with respect to gypsum for Wattis watershed. Quantitative implications of dilution effects on water saturated with minerals are still uncertain.

Recommendations/Part I

For future consideration, the following items are recommended:

(1) Conduct studies to validate the general applicability of USLE in western desert lands for individual storm events.

(2) Perform infiltration studies for soils of suspected runoff areas. This will improve the capability for runoff prediction.

(3) To quantify channel solute pick-up, a geochemical study of the surface materials of the lower walls and the bottom of the channels should be carried out. A study is required to clarify the issue of dilution effects on water saturated with gypsum and calcite.

(4) If this study is to repeat again, we recommend using a Stevens type A-35 recorder for Grassy Trail Creek site in order to cover the 2 to 3 day time base of storm events.

(5) Gully plug surveys will also contribute to USLE validation. This would require a recording raingage and surveying of changing bottom topography. A field scale computer program, called **CREAMS**, is now avilable and could be tested for field watershed studies.

(6) There are still shortcomings associated with automatic sampling. The machine sampling procedures should be designed to switch on in a more predictable fashion. There should be more flexible options of sampling sequence. Before the apparent drawbacks of machines are overcome, hand-sampling still has to be used to enhance the value of machine samples.

Conclusions and Recommendations/Part II

Results of this study are summarized in section 1.2 of the Part II report. Baseflow monitored at Desert Seep Wash contributes a considerable portion of total total salt load of the basin. Baseflow at Desert Seep Wash station alone contributes about 30 % (56600/195000) of the total salt load passing through Woodside station. However, how much of this 56,600 tons of salt comes from irrigated areas and how much from the un-irrigated areas remain unresolved. The answer to this question will also answer the question as to how much of the baseflow-related salt load is controllable.

At issue here is whether there exists an extensive aquifer which transmits natural water from both the irrigated and the un-irrigated areas to recieving streams in the form of baseflow. There is not sufficient data to make any determination. This can only be determined from a field monitoring program. A well conceived groundwater monitoring plan and some computer analysis can quantify the basin wide groundwater flow condition and determine how much of the baseflow salt load (e.g. 56,600 tons at Desert Seep Wash) is from un-irrigated area and how much from the irrigated area.

The cross-correlation between the irrigation flow diversion and baseflow at receiving streams points out the residence time of deeply percolated water in irrigated lands. It also suggest a method for studying the net irrigation efficiency. That is, if we know the time lag between the water supply time series and the return flow time series, it is feasable to line up the two time series and study the net irrigation efficiency.

A **UINTEX** Report, TP821

A Study of Runoff and Water Quality Associated with the Wildlands of The Price River Basin, Utah

Part I:

Storm Runoff and Water Quality in Selected Ephemeral Streams of The Price River Basin, Utah

Prepared for
U.S. Department of the Interior
Bureau of Land Management
Special Studies Division
Denver Federal Center
Denver, Colorado 80225

by
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4568 Highland Drive, Suite 240
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July, 1982

Contract Number YA553-CT1-1064

List of Abbreviations

A-F	Acre-feet
BLM	Bureau of Land Management
cfs	Cubic feet per second
EC	Electrical Conductivity, expressed in micro umhos/cm
ft	Feet
g/l	Grams per liter
IAP	Ionic Activity Product
in	Inches
K	Equilibrium Constant of a Mineral in Solution
kg	Kilograms
km	Kilometers
le	Liters
lps	Liters per second
meg	Milliequivalent
mg/l	Milligrams per liter
ML	Miles
NOAA	National Oceanic and Atmospheric Administration
Q	Discharge, expressed in lps, 1000 lps, or cfs
RO	Total Runoff, expressed in inches or A-F
SCS	Soil Conservation Service
SDR	Salt delivery rate, in tons per year
SI	Saturation Index, log {IAP/Kc}
SS	Suspended sediment
TDS	Total dissolved solids, in mg/l or g/l
TS	Total Solids, including TDS and suspended solids, expressed in mg/l or g/l
USGS	U.S. Geological Survey

Conversion Table

1 cubic ft	=	28.3	le
1 ton	=	907.18	kg
1 cfs	=	28.3	lps
1 A-F	=	1.2327	million le
1 square mile	=	2.59	square km
1 mile	=	1.609	km

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CHAPTER 1

INTRODUCTION

This report documents the results of a study of storm runoff and water quality in the Price River basin, Utah, from August through December of 1981. The study covers one season of field data collection for 4 watersheds, effectively from the 1st of September through the 10th of November, and interpretation of the collected results. The four watersheds are: Coal Creek Tributary (to be referred to as Coal Creek), Soldier Creek Tributary (Soldier Creek), Wattis watershed, and Grassy Trail Creek watershed. The field program also includes weekly monitoring of 18 selected sites for non-storm runoffs the results of which are reported in Part II. Locations of the monitored sites are shown in Figure 1. Major characteristics of the gaged sites are summarized in the following table:

Table 1: Characteristics of gaged watersheds

Watershed	Acres	Min Elev	Max Elev	Ave Slope
Wattis	3130	6075′	9072′	14.7 %
Soldier Creek Tributary	800	5690′	6120′	10.9 %
Coal Creek Tributary	262	5760′	6300′	9.93 %
Grassy Trail Creek	185000	4980′	10000′	not estimated

1.1 Scope of Study

The purpose of this study is to measure storm runoff and water quality from BLM-adminsitered wildland. Each watershed was chosen for its unique charateristics. Wattis was chosen for its steep, highly dissected Mancos Shale hillside slopes. The Coal Creek (CC) watershed was contour furrowed. The Soldier Creek (SC) watershed has catchment features comparable to those of CC but was untreated. Grassy Trail Creek(GTC) was selected to monitor the general nature of thunderstorm runoff and salinity from a large watershed.

1.2 Specific Objectives

The specific objectives of this study are to:

(1) Determine the relationships between precipitation (P) and runoff (RO). Evaluate the effectiveness of curve numbers (CN) as a reasonable expression of these relationships.

(2) Identify relationships between total solids (TS) and runoff.

(3) Identify relationships between total dissolved solids (TDS) and runoff.

(4) Determine if relationships exist between TDS and TS.

(5) Attempt to quantify the relative contributions to salt loading from in-channel processes.

(6) Evaluate the usefulness of USLE in assessing soil loss and salinity.

1.3 Literature Review

General background of salinity issues has been discussed in many salinity-related reports. For an understanding of the regional perspective, we mention three publications:

(1) U.S. Bureau of Reclamation's "Salinity Update, special edition, 1981" which provides a concise summary of socio-political issues involved (20).

(2) U.S. Bureau of Land Management (19) gave a 1977 salinity status report on "The Effects of Surface Disturbances on the Salinity of Public Lands in the Upper Colorado River Basin." The report covered all major aspects of natural, land-use factors, and dealt with engineering and economic aspects of salinity control measures for public land. Generalized geologic, soil, and salt load information are useful.

(3) Mundorff (8) reported the chemical quality of surface water in the upper, central and lower basins of the Price River. The report points out that the upper basin presents little salinity hazard. The central basin consists of exposed marine shales and the area is also fairly heavily irrigated with water diverted from the upper basin. Water quality deteriorates considerably as the stream crosses the central basin, typical TDS increasing from 400 mg/l to 2400 mg/l. This degradation of water quality was attributed both to irrigation return flows and salt loading from natural environment. The lower basin contributes little runoff and has little amount of water use, therefore no major improvement or deterioration of water quality is evident.

Ponce (11) performed simulated rainfall-runoff studies on infiltrometer plots and microwatersheds. The plots and microwatersheds are 2.5 square feet and 40 square feet in catchment area respectively. Results of their studies were also summarized in **Hawkins et. al.** (2). Some important findings include:

(1) The precipitation-runoff relationships were very consistent if evaluated in terms of Curve Numbers. Most of the field tests, on the plots or microwatersheds, resulted in a CN at low 90's.

(2) The study points out the influence of geologic types on the TDS and SS concentrations. For plot studies, the three high TDS producing geologic units were:

Alluvial deposits	1557 mg/l
Mancos undivided	529 mg/l
Lower Blue Gate	174 mg/l

and the four high SS producing geologic types were:

Green River	7.36 g/l
Mancos Undivided	7.12 g/l
Lower Blue Gate	7.02 g/l
Middle Blue Gate	6.95 g/l

(3) Salt-sediment ratios were reported as follows:

Alluvial Deposits	0.256
Upper Bluegate	0.015
Middle Bluegate	0.019
Lower Bluegate	0.027
Musuk	0.015
Tununk	0.053
Mancos Undivided	0.063

Ponce's study resulted in parametric salt loading functions. One of the salt loading functions predicts that less than 1% of total salt load in the Price River basin is contributed from the wildland, overland flow.

White (21) studied runoff and water quality in microchannels ranging from 100 feet to 300 feet in length. Eight sites were selected among Mancos Shale members. General findings were similar to Ponce's study. Mean salt:sediment ratios were found to be dependent on geologic types. For microchannels, the TDS

and SS concentrations are:

Geologic Type	No Test	TDS (mg/l)			SS (g/l)		
		Min	Max	Med	Min	Max	Med
Mancos Undivided	12	215	1580	685	4.2	19.8	14.0
Upper Blue Gate	3	153	657	389	15.4	19.2	18.1

Laronne and Schumm (5) studied dissolution behavior of soil samples taken from surficial alluvium and Mancos Shale from three basins in western Colorado and one from Price River Basin, Utah. The latter is the North Miller Creek watershed (or the Wattis watershed as identified in this study). Some imporrtant results are:

(1) The mean soluble mineral content of Mancos Shale derived from hillslopes is 1.99 percent. The mean for terraces in Wattis watershed is 0.62 percent. Watti's watershed alluvium is rich in soluble minerals(10%) due to its physical closeness to Mancos Shale.

(2) Wattis watershed is "a bedock channel incised in the slightly permeable Mancos Shale formation, most of the overland flow reaching the channel does not percolate into the bed, and bed materials dry primarily by evaporation thereby forming very saline crusts."

(3) Water quality of storm runoff in ephemeral channels is greatly influenced by the salt content of bed and lower gully wall crust materials.

"The crusts of the lower and the upper Mancos Shale gully walls of Wattis watershed contain 1.07 and 0.76 percent soluble minerals. The lower wall comes in contact with water frequently enough that transport of solutes to the outer surface is more pronounced than in the upper wall."

(4) The study also points out the important implications of chemical disequilibrium of sulfate minerals. By comparing dissolution characteristics of 1:99 and 1:9 sediments:water mixtures, 95 percent of the samples tested show an increase in mineral dissolution for the more diluted 1:99 mixtures, whether the solution is saturated or undersaturated with respect to gypsum. Continued release of over saturated gypsum upon dilution is readily understandable. A hypothesis of mineral coating was suggested for the dilution effect in undersaturated gypsum solution.

(5) In view of the above mentioned dilution effect, salt load estimates from EC measurement alone may be quite misleading. Water of storm runoff with high sediment content (100,000 g/l or more) could release substantially more salts when mixed with fresher water downstream, than predicted from EC measurements.

(6) The study also showed that "the saline crust surface soil crust salinity increases as the permeability decreases and as the soluble mineral content of the underlying material increases."

Shen et. al (13) reported a study on the role of sediment in non-point source salt loading within the Upper Colorado River Basin. Both laboratory investigations and a hillslope study with simulated rainfall were performed. Essential results pertinent to this study are listed below:

(1) Gypsum is identified as the major soluble mineral in Mancos Shale; varying amounts of less soluble carbonates and more soluble sodium magnesium sulfates are also present. Sulfate minerals are enriched in efflorescent crust.

(2) Hillslope studies show that solute pick-up is initially high but decreases asymptotically after an early maximum is reached due to the combination of (a) surface flushing effect (b) decrease in erosion rate, and (c) decrease in solute concentration gradient between the bulk solution and the soil solutions.

(3) The TDS may reach a second maximum due to a combination of (a) rilling or downcutting of rills with accompanying increase in sediment production, and (b) erosion and transport of deeper-lying, more saline Mancos Shale material.

(4) The TDS has been shown to strongly depend on sediment transport. This conclusion was based on the following observations:

(a) Concurrent peaking of TDS and SS
(b) Agreement in time of rilling and time of maximum EC
(c) Increase of solute concentration in unfiltered runoff samples.

(5) TDS increase downslope and downchannel during direct runoff generation. Solute pick-up also increases when underlying shale material that contains a high soluble mineral content is eroded. TDS increases with an increase in hillslope inclination. Average conductance at the two hillslope test sites maybe expressed as linear regression of slope (in degrees) with correlation coefficient close to 0.9.

(6) Three thunderstorm and three snowmelt runoff events under natural conditions were sampled at West Salt Creek, in Grand Valley, Colorado. The results reveal that TDS does not vary systematically with discharge. Initial flushing produces much higher TDS than the remainder of the storm event.

(7) TDS is high, and saturation with respect to gypsum is ordinarily reached. On the other hand, TDS of snowmelt runoff is typically very low.

The present study was preceded by a study by Utah State University from 1977 to 1980. **Riley, et. al.** (9) report the results of USU's study. Four storm events each were gathered for Soldier Creek, Wattis and Grassy Trail Creek watershed. Five storm runoff events at Coal Creek were gathered. Because of the limited number of storm events, and somewhat incomplete data on water quality the conclusions were mostly tentative.

Jackson and Julander (3), based on simulated rainfall studies on Price River Basin, found that steep-sloped Manco shale uplands are the major contributors of sediment and salt on a per area basis. This was due largely to erosional instability of the steep shale slopes, and the predominance of rilling during runoff-producing events. Rilling accounted for approximately 80 percent of the sediment produced on this landform type. On the gentle slopes of the shale landscape, a thin, friable crust layer was relatively resistant to the erosional effects of raindrop impact and overland flow. This resulted in relatively low values of suspended sediment and EC in runoff, in spite of the poor infiltration properties of the basin. On the correlation between salt and erosion rates Jackson and Julander argue that an explicit relationship between sediment transport and EC of the runoff would be a function of sampling location in the channel. The reason being that some larger sediments would settle out of the flow, as indicated by channel aggradation. At the same time, relatively high quality water would be contributed from surrounding flat areas, resulting in a dilution effect. This, combined with sequences of aggradation and degredation in ephemeral washes would probably make correlations between sediment concentration and TDS variable in space and between individual storms.

1.4 Background Summary

Based on the above-mentioned publications, a general background of runoff-salinity in ephemeral streams is summarized below:

(1) The major soluble mineral of Mancos Shale is gypsum,

with varying quantities of other sulfate minerals. Mean soluble mineral content of Mancos Shale is about 2%. It could vary from 1.5% for Upper Bluegate to 6.3% for Mancos Undivided.

(2) Upon dilution, an increase in dissolution of gypsum (whether it is saturated or undersaturated) was observed in the laboratory and a similar effect is expected under natural conditions.

(3) For overland flows, solute pick-up increases as sediment concentration increases.

(4) Solute pick-up increases as hillslope increases.

(5) Heavy solute pick-up in channels is associated with physical closeness to Mancos Shales. Channels or flow pathways through exposed Mancos Shale bedrock or thin alluvium underlain with Mancos Shale are salinity hazard areas.

(6) There is a wide range of difference in the estimates of percent total salt load contributed from wildland: from 1% to 50%.

CHAPTER 2

METHODS OF INVESTIGATION

Many natural parameters are expected to influence runoff and water quality. Attempts were made to include as many parameters in the analysis as the available data permit. Many of those parameters investigated by previous investigators are included in this study. This Chapter describes the general study methods. Organization of data and interpretation of results are discussed in Chapter 4.

2.1 Field Instrumentation

At Wattis and Coal Creek, type-F stage recorders were used to record water levels in a cutthroat flume. Water levels in the flume are related to discharge by the rating curve for the flume. A watch-dog switch was installed in the type-F recorder to activate the recorder and an ISCO automatic water sampler when water level in the stilling well reached a pre-selected level. The sampler pump was programmed to sample at predetermined time intervals.

The Soldier Creek gage site was located at a highway culvert. A pressure transducer was originally installed at the downstream end of the culvert by Utah State University. In place of the pressure transducer a new stilling well with a type-F recorder was installed at the upstream end of the culvert. The rating curve for the new gage station was developed from a backwater computation on the basis of the rating curve for the original section. An ISCO sampler was programmed to start sampling at predetermined water level and continue sampling at predetermined time intervals.

At Grassy Trail Creek gage site, the original pressure transducer was replaced with a stilling well and type-F recorder. The ICSO sampler was programmed to sample at a predetermined water level. Discharge is obtained from USU's rating curve, last surveyed on August 7, 1980.

2.2 Soil Characterization

Generalized soil characteristics for the study area were used in this study. Erosion characteristics and salinity information of soils were obtained from U.S. Soil Conservation Service reports (14, 15, 16).

The mapping units of these soil surveys were described in soil phases, a high order category of a soil series. A soil

series is a group of soils that have major horizons similar in thickness, arrangement, texture and other important factors. However, the soils of one series may differ in texture of surface layer and in slope, stoniness, salinity or some other characteristics that affect the use of soil. On the basis of these differences, they are divided into phases. The name of the phase indicates the dominant feature that affects its use. Soil characterizations are given in Figures 2 through 4 and Tables 2 through 4 for Wattis, Soldier and Coal Creek watersheds. A summary listing of soils for Grassy Trail Creek watershed is shown in Table D1 in Appendix D. Some explanations regarding the notations used in the tables are given below:

EC is the amount of soluble salts in the soil expressed as the electrical conductivity of the saturation extract at 25 degrees C.

The erosion factor K is a numerical expression of the potential erodibility of the soil on a graduated scale of .10 to .64 divided into 12 classes. Mainly soils with a K value class of .2 or more are considered as low erodibility; .2-.4 is moderate and more than .4 is high erodibility.

Hydrologic Soil Group is used to designate grouping of soils to estimate runoff from rainfall:

A. (Low runoff potential) Soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well to excessively drained sands or gravels. These soils have a high rate of water transmission.

B. Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.

C. Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.

D. (High runoff potential) Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

Table 2: Soil Characteristics of Wattis Sub-Watershed

Area = 4.90 square miles (3130 Acres)

Soil Name	Map Unit Symbol	Area Sq. Mi.	EC (mmhos/cm)	Permeability Depth in/hr	Depth (in)	Slope %	Erosion Factor K	Hydrologic Group
Badland	BL	.84		Shale outcrop		Steep to very steep	Active erosion	
Chipeta Silty Clay Loam	CHD2	.52	2-8 8-16 15+	.06-.2	10-20	8-15	.43	D
Featherlegs Stony Loam	FEC	.58		.6-2.0 2.0-6.0	>60	3-8	.28	B
Haverson Silt Loam	HCC	.15	<2	.2-0.6 .2-2.0	>60	3-8	.49	B
Shingle-Chipeta-Badland Complex	LFG3	1.24	<2-4	.6-2.0	10-20	30-70	.17-.24	D
Shingle-Ildefonso Badland Complex	NJG2	.11	7+ .2-0.6	2.0-6	15-20	50-70	.2 -.43	C
Lazear-Shingle Complex	NME2	.15	<2	.6-2.0 2.0-6	5-20	3-30	.32	D
Shingle-Badland Complex	NNE2	.28		2.0-6 .6-2.0	10-20	8-30	.24	C
Doney Shaly Silt Clay Loam Eroded	UFF2	1.02		.2-0.6	20-40	15-40	.32	C

Table 3: Soil Characteristics of Soldier Creek Sub-Watershed

Area = 1.25 square miles (800 Acres)

Soil Name	Map Unit Symbol	Area Sq. Mi.	EC (mmhos/cm)	Permeability Depth in/hr	Depth (in)	Slope %	Erosion Factor K	Hydrologic Group
Ildefonso Gravely Loam	IDC	.49		.2-0.6	>60	3-8	.28	B
Locker-by Cragola	LDG2	.15		2.0-6.0 .6-2.0	20-40	8-60	.17-.37	B
Ravola Silt Loam Eroded	R1A2	.36	<2 2-8 2+	.2-0.6	<60	0-3	.49	B
Shingle Very Shaly Loam	NHC	.25		2.0-6.0. .2-0.6	10-20	3-8	.28-.37	C

Table 4: Soil Characteristics of Coal Creek Sub-Watershed

Area = .41 square miles (262 Acres)

Soil Name	Map Unit Symbol	Area Sq. Mi.	EC (mmhos/cm)	Permeability Depth in/hr	Depth (in)	Slope %	Erosion Factor K	Hydrologic Group
Gullied Land	GU	.04		Provides drainage for adjacent soils		Deep gullies (10'-20') are formed by runoff. Erosion of saturated soils causes the side banks of the gully to topple and widen the gully (50-150')		
Persayo-Chipeta Association	PCE2	.08	2-16	.06-2.0	12-17	1-20	.49	D
Ravola Loam	R1B	.17	2-8	.6-2.0	60	1-3	.49	B
Sanpete Gravelly Sand Clay Loam	S1D2	.03	<2	.6-2.0 2.0-6.0	>60	3-10	.28	A
Shaly Colluvial Land, High rainfall	Snh	.09				Steep	Moderate to severe erosion	

2.3 Runoff Source Areas

To study the overland flow process on different soils within the study watersheds, a computer program was developed to simulate the variation of runoff producing process with rainfall intensity, duration, and drainage characteristics. A simple geometric configuration (straight slope) was assumed for this analysis. Appendix C gives the description of the computer simulation. It should be noted that in applying this simulation, the infiltration characteristics, a, b, in eq. (1) in Appendix C1, are the intercept and slope of the best fit line to the infiltration vs. time data. The only infiltration data available were for Ravola loam and Chipeta-Persayo loam on irrigated plots. For all other soils values of the regression parameters were rough estimates mostly using the saturated permeability values listed in Tables 2 to 4. The program assumes that rainfall intensity should be higher than saturated permeability to produce any runoff. Other parameters needed for this study are average slope and length and width for each soil unit identified in Figures 2, 3, and 4.

By varying rainfall intensity, slope, and/or infiltration characteristics, runoff producing conditions are identified. The results of these computations show estimated source areas contributing to overland flow. (Rainfall intensities used in the simulation were somewhat higher than the actual values encountered in this study). In our computations, the antecedent soil moisture condition was assumed dry on all soils. Areas producing runoff according to simulation are identified as dotted areas in Figures 5 through 7 for Wattis, Soldier Creek, and Coal Creek. FORTRAN listing of the computer program is attached in Appendix D.4 (microfiche).

2.4 Soil Loss Estimates

The Universal Soil Loss Equation (USLE) was applied to quantify the relative erosivity of runoff contributing areas within the study watersheds. The USLE is a parametric approach which relates potential soil loss with several parameters:

$$A = RKLSCP$$

where **A** is the computed soil loss per unit area, expressed in units seleced for **K** and for period selected for **R**.
R, the rainfall and runoff factor
K, the soil erodibility factor
L, the slope-length
S, the slope-steepness factor

C, the cover and management factor
P, the support practice factor

Each USLE parameter is independent of the others. The equation was developed initially on plots on cultivated lands, but is also used to estimate soil loss on natural lands. The rainfall factor **R** is an index of the kinetic energy of rainfall. The rest of the terms are related to soil erodibility.

The factor **K** is taken from the Soil Conservation Service (14, 15, 16) and factor **P** is one for untreated runoff source areas. The factor **C** is estimated from descriptions of the vegetation (14, 15, 16), from a study of the aerial photos provided by BLM, and Table 10 of USDA-ARS (17).

The review of the literature indicates that solute pick-up increases as slope increases. In fact a linear regression was noted by Shen et.al (1981). This is consistent with the USLE's principle: sediment loss is proportional to slope.

USLE is used to compute potential soil loss resulting from observed rainfall. The question of actual delivery of sediment, or gradation of sediment, however, is not answered by USLE.

2.5 Chemical Analysis and Saturation Index

Water samples were analyzed by Brigham Young University's Environmental Analysis Laboratory. All the analytical work was certified (see Appendix D.2). The analytical data were futhered evaluated to study the extent of equilibrium with respect to major sulfate minerals.

Using results of 64 samples analyzed for ion species, a set of linear regression equations was developed to relate EC and TDS. The following equations were used in load computation:

Ranges of EC	Linear Regression	Correlation Coefficient
0-600	**TDS** = 0.067***EC** - 4.29	0.97
601-1500	**TDS** = 0.81 ***EC** - 97.23	0.97
1501-3000	**TDS** = 0.87 ***EC** - 220.74	0.91
3001-25000	**TDS** = 1.08 ***EC** - 979.23	1.00

Mineral saturation index (SI) is a measure of the thermodynamic state of a solution relative to equilibrium with a specified solid-phase mineral. For a solution to be in equilibrium with solid-phase gypsum, the following reaction must be in equilibrium:

$$CaSO_4(Solid) = Ca^{++} + SO_4^{--}$$

The mass action equation for the above expression is:

$$\{Ca^{++}\}\{SO_4^{--}\} = K_c$$

since solid-phase mineral activities are taken by convention to be unity. If the product, $\{Ca^{++}\}\{SO_4^{--}\}$, called ion activity product (IAP), is less than **Kc**, dissolution will occur. If IAP > **Kc** then precipitation will occur. The index SI= log (IAP/**Kc**) is a measure of departure from equilibrium. Thus SI = -1 means IAP/**Kc** = 1/10 and SI = +1 means IAP/**Kc** = 10. The closer the value SI approaches zero, the closer the solution is to reaching saturation with respect to the specified mineral.

Chemical equilibrium computations of major sulfate minerals, gypsum and anhydrite, are performed in this study using computer program WATEQF, developed by Plummer et.al (1976).

CHAPTER 3

SITE DESCRIPTIONS

Four watersheds selected for storm runoff studies are described in this chapter. Major characteristics of the gaged watersheds were shown in Table 1 in Chapter 1.

The **Wattis** watershed is representative of medium size ephemeral drainage basins originating in steeply dissected Mancos Shale upland and traversing exposed bottomland shale. The basin area is 3130 acres and the main channel length is seven miles. Elevation ranges from 6075-9072 feet. At the gage, the channel is a third order stream.

The **Soldier Creek** and **Coal Creek** watersheds are typical small size (800 and 262 acres respectively) ephemeral drainage basins with medium topographical relief (elevation ranges from 5700-6200 feet). The drainage channels originate in sandstone formations in the foothills of the Book Cliffs and then traverse moderately dissected Mancos Shale. At the gage sites, the channels are second order streams. The two basins have signficantly different channel characteristics. Soldier Creek has well trenched (20-foot wide and 40-foot deep) channels, while the main channel of Coal Creek is 10′ wide by 20′ deep. Some side channels to Coal Creek appear to be in an incipient stage of development. The lowland areas of Coal Creek Tributary were contour furrowed approximately 16 years ago.

The **Grassy Trail Creek** watershed represents a large drainage basin covering 185000 acres. The stream originates in the foothills of the Book Cliffs and traverses a variety of geologic, soil, vegetative and land-use features.

3.1 Wattis Drainage

Soil distribution in the drainage was recently surveyed by SCS and a map of soil types and the drainage pattern is shown in Figure 2. Soil descriptions, and runoff and erosion related data are tabulated in Table 5.

Shingle-Chipeta-Badland and Chipeta-silt, clay loam are on very steep slopes, and severely eroded. Derived mainly from shale, they are shallow and well drained. Present vegetation is birchleaf mountain mahogany (Cercocarpus montanus), serviceberry, shadscale (Atriplex confertifolia), and pinyon (Pinus edulis). Surface runoff is very rapid and the erosion hazard is very high. The subsoil and plant roots are exposed in many areas, very little of the surface litter is remaining and surface rock fragments exhibit some movement. Rills 3-6 inches deep occur at 5 to 20 foot intervals.

On more moderate slopes, shallow soils with high erosion hazard are underlain by shale. Soil loss occurs both as sheet and channel erosion. There are infrequent rills and a few relatively stable gullies. Vegetation consists of juniper (Juniperus osteosperma), galleta grass (Hilaria jamesii), indian rice grass, and blue grama (Bouteloua gracilis). On mountain foot slopes soils are moderately deep and well drained. Permeability is moderately slow. Surface runoff is rapid and erosion hazard is high. Gullies are numerous and well developed with active erosion along 10 to 50 percent of their length. Rills are 1/2 inch to 6 inches deep and occur at intervals of 5 to 10 feet in exposed areas. Present vegetation is dominantly pinyon (Pinus edulis), salina wildrye, juniper (Juniperus osteosperma), low sagebrush, and rabbitbrush (Chrysothamnus naueosus).

Badlands consist of steep and very steep nearly barren beds of actively eroding shale, shale interbedded with sandstone, shale interbedded with gypsum, and occasionally small areas of shale capped by sandstone. The landscape is dissected by numerous intermittent drainage channels. Runoff is very rapid. The sediment potential is high during intense summer thunderstorms. Badlands support only very sparse salt tolerant vegetation.

Larrone and Schumm (5) performed a fairly thorough study of the various soils in this drainage. They indicated that, because of the low permeability of the bedrock channel, the mean salt content of bed crusts developed in the drainage is 10.10 percent soluble material compared with 0.94 percent in the bed proper. The crusts of the lower and upper Mancos Shale gully walls contain 1.07 and 0.76 percent soluble material(5).

3.2 Soldier Creek Tributary

The distribution and description of soils is shown in Figure 3 and Table 3. The predominate soil on this watershed is a Ravola silt loam on gentle slopes. It is very deep and well drained and derived mainly from shale and sandstone. Surface runoff is slow and erosion hazard is high. The erosion is increased due to runoff from surrounding shale hills. Watershed areas on the Ravola series are dissected by gullies 5 to 20 feet deep at 50 to 200 feet intervals, fed by rills 5 to 20 feet apart in a dendritic pattern.

Included in soils of this area is Shingle very shaly loam on slopes 3-8 percent. These are shallow, well drained soils on dissected shale hills. They are derived dominantly from shale. Present vegetation is mainly shrubby eriogonum, black sagebrush,

salina wildrye and Indian rice grass (Oryzopsis hymenoides). Runoff is medium, and the hazard of water erosion is moderate.

Lockerby-Gragola soils occupy some parts (Terraces) of this watershed. They are derived from shale and sandstone and are moderately deep and well drained. Vegetation is mainly black sagebrush, galleta grass (Hilaria jamesii), Indian rice grass (Oryzopsis hymenoides), shadscale (Atriplex confertifolia), blue grama (Bouteloua gracilis), yellowbrush, and bottlebrush squirreltail. Runoff is rapid and the hazard of erosion is high.

Ildefonso gravelly loam soils are very deep and are derived mainly from sandstone and shale on slopes (3-8 percent). Present vegetation is pinyon (Pinus edulis), juniper (Juniperus osteosperma), birchleaf, mountain-mahogany (Cercocarpus montanus), and salina wildrye. Surface runoff is medium and erosion hazard is high.

3.3 Coal Creek Tributary

Figure 4 and Table 4 describe the distrubtion of soils in the drainage. Areas marked as R1B and S1D2 are contour furrowed.

This watershed mainly consists of Ravola loam on moderate (1-3 percent) slopes and Persayo-Chipeta Association on steeper slopes (1-20 percent). Ravola loam soils are very deep, well drained. Salinity is generally slight to moderate. Runoff is medium and erosion potential is moderate. Persayo-Chipeta soils contain weathered fragments of shale increasing with depth. Roots penetrate to the shale and then they spread horizontally. These soils are used mainly for spring and fall grazing. Sheet erosion is active, and in many places shallow gullies have cut into the shale. Other soils of this tributary are shaly Colluvial land on very steep slopes with moderate to severe erosion and vegetation consists of juniper (Juniperus osteosperma), pinyon pine (Pinus edulis), and some big sagebrush and galleta grass (Hilaria jamesii).

3.4 Grassy Trail Creek Drainage

Since there were no precipitation records gathered for this drainage, we did not attempt to study the soil distribution and erosion in detail. No maps were prepared for the drainage. A tabulation of soil types is provided in Table D1 in Appendix D.

CHAPTER 4

STORM RUNOFF AND WATER QUALITY

Intensive sampling of storm events began on the 3rd of October after which a sequence of storms followed. Prior to the series of storms in October, there were several major storms in August and one on the 5th of September.

The Belfort raingages arrived in Salt Lake City on the 6th of October and were installed on the field on the 9th. There is one raingage each in Wattis, Coal Creek Tributary, and Soldier Creek Tributary. None is installed in Grassy Trail Creek. Precipitation records for the month of October are shown in Figure 8. NOAA's records at Price Warehouse are also included for comparison.

In this study a total of 20 storm events were monitored: seven for Wattis watershed, six for Soldier Creek Tributary watershed, five for Coal Creek Tributary watershed and two for Grassy Trail Creek watershed.

Each storm event is identified by a letter W, S, C, or G to designate Wattis, Soldier Creek Tributary, Coal Creek Tributary or Grassy Trail Creek respectively. The letter is then followed by number 81 for the year 1981, then two-digit month followed by two-digit date of the storm event.

4.1 Organization of Results

Because the watersheds under study have streams of at least second order and cover areas more than 260 acres, spatial variation of natural parameters is expected. Some factors, not important in plot studies, are important watershed processes such as mass wasting, channel encrustation, spatial distribution of precipitation, soil types, and basin geomorphology.

Many possible combinations of parameters were paired to examined possible relationships. Most of these relationships were developed by previous investigators. In order to establish some functional relationships (or lack of them) among parameters the following questions are posed:

(1) How are precipitation (P) and runoff (RO) related? What is the role of CN?

(2) Are total solid (TS) and runoff related systematically?

(3) How are total dissolved (TDS) and runoff related?

(4) Is there any relation between TDS and TS?

(5) Can the overland processes and the in-channel processes be identified? Can they be quantified?

(6) How useful is USLE in assessing soil loss?

With these questions in mind, data of the storm events are organized in graphs and tabulated summaries. The graphs include plots of Q, TDS, TS, SI, and TDS/TS ratio along the same time scale.

The tabulated results include, referring to Tables 2 through 5, the following items:

(1) Runoff volume(RO) computed by integrating the hydrograph and expressed in acre-feet.

(2) TDS load, obtained by integrating the product RO*TDS, expressed in tons.

(3) TS load, calculated from an integration of RO*TS, also expressed in tons. Note TS includes both the dissolved and the suspended solids.

(4) Average salt/solid ratio is expressed as percent. This is obtained from the ratio TDS load/TS load.

(5) Discharge-averaged TDS is obtained by dividing the TDS load by runoff volume.

(6) Discharge-averaged TS in mg/l is calculated from the ratio of TS load and runoff volume.

(7) Soil loss estimates in tons is calculated from the Universal Soil Loss Equation for using the recorded precipitation.

(9) Total precipitation in inches are listed.

(10) Runoff/precipitation ratio's based on the runoff source area are listed. The numbers are obtained by forming the ratio between runoff volume in inches and precipitation in inches. The number listed is dimensionless.

(11) Curve number is calculated from a pair of precipitation P and runoff RO both in inches. The formulas used are:

$$CN = 1000/(10+S)$$
$$S = 5P[1+2t - \text{square root}(4t * t + 5t)]$$

where $t = RO/P$

(12) and (13) are similar to (10) and (11) respectively, but they are based on the total watershed area.

(13) Pertinent comments are given to specify the completeness of samples.

(14) Method of sampling: either manually or ISCO sampled.

Some notes on CN are in order. The curve number CN has been used widely by many previous investigators as an index of the P-RO relationship. It was found that for CN, small RO/P ratios and small values of P, the associated value S is close to one or less than one. This makes the CN value close to 90. In this range of precipitation, a "high" value CN at 92 does not imply high runoff at all. Figure 9 shows the relationship between P, CN, S and Retention with Ponce's and Lusby's field data as well as definitions of the terms; it demonstrates that all the storm events with precipitation less than 2 inches or so would have CN between 90 and 100 even if the runoff is quite low.

It is suggested that for precipitation less than 2.0 inches, a CN with four significant digits is necessary to recover accurate relationships between P and RO. Furthermore, in this range of precipitation, the notion of high CN implying high runoff needs to be interpreted with caution.

CN is an implicit way of relating P and RO. Presumably a watershed should have a fixed value of CN. To obtain CN for a watershed, a mean CN value is sought among the available P-RO data pairs. The precision of the mean is expressed by the standard deviation. From the mean CN value, P and RO are related for future storms according to the definition of CN.

Alternatively, a relationship between P and RO may be established from data. A typical relation may be a linear. This is suitable if the range of rainfall of interest is not large (between 0 and 3 inches). The fit for a linear regression can be measured by the correlation coefficient. Both CN and linear regression will be used in the analysis of data.

In the following discussions, storm events are organized according to watershed. The hydrograph, the TDS-, TS-, SI-, and TDS/TS-graphs will be reviewed under the heading "Description of Storm Event". Some general interpretation will be made from the

graphs. More detatiled interpretation of the graphical results and the tabulated results are then included in "Interpretation of Results".

4.2 Results/Wattis Watershed

Since Laronne and Schumm (5) included this watershed in a study of dissolution potential, much better background information exists. There are seven storm events monitored in this study, some of them were carefully hand-sampled. Overall, Wattis watershed has the most complete set of data. More in-depth discussions are thus possible.

According to Laronne and Schumm (5), the channel of this watershed is mainly composed of exposed Mancos Shale bedrock. It is assumed in the discussion that most of the sediments from overland erosion would be transported past the gaging station, leaving few deposits along the channel. Also noted are the facts that the soluble minerals of surficial Mancos Shales constitute about 2% of the soil samples, and salt crust has 10% soluble minerals. These figures are important reference numbers in later discussions of overland and channel solute pick-up.

The soils identified as badland (BL) are usually saline because of the shale outcrop (see Table 2 on page 10). Chipeta soil is not saline by itself, but it is underlain by saline shale within a 10-inch depth. Thus, Chipeta is practically a salinity hazard soil. Other soils listed in Table 2 are not considered saline.

4.2.1 Description of Storm Events

The description of each individual event is presented below. The discussions should be accompanied with Figures W1 through W7. A summary of storm events to be discussed is given in Table 5.

TABLE 5: WATTIS DRAINAGE STORM SUMMARY

	Storm	W810821	W810905	W811003	W811011 AM	W811011	W811016	W811017
(1)	Runoff volume (RO), A-F	5.57	2.545	2.627	8.318	2.475	11.51	6.844
(2)	TDS load, tons	47.2	7.52	19.6	NA	5.43	21.5	12.9
(3)	TS load, tons	1643	205	472	NA	226	601	183
(4)	Average salt: Solid ratio, %	2.87	3.67	4.15	NA	2.41	3.58	7.05
(5)	Average TDS, mg/l	7682	2177	5495	NA	1616	1365	1391
(6)	Average TS, mg/l	267684	59292	132108	NA	67158	38414	19699
(7)	Soil Loss, (USLE) Tons	NA	NA	NA	1173	340	530	606
(8)	Precipitation (P), in	NA	0.17	.2	.5	0.1	.6	.17
(9)	Runoff/Precip ratio (source area)	NA	0.104	.089	.112	.167	.130	.272
(10)	CN (Source area)		96.26	95.35	90.03	98.16	88.98	97.86
(11)	Runoff/Precip Ratio (whole area)	NA	0.0560	0.0476	0.0601	0.0896	0.0698	0.146
(12)	CN (Whole area)		95.37	9.36	87.74	96.10	86.22	96.80
(13)	Completeness of Samples	C	MF	C	PT	C	C	C
(14)	Channel Solute Pick-up, tons	5.6-7.8	N	4.0-8.0	N	0.0	N	small
(15)	Sampling method	M	M	M	ISCO	M	ISCO	ISCO

Notes:
C = Completely sampled
PT = Partically sampled
MF = Records for initial part of storm event not sampled
NA = Not available
M = Manual
N = Unknown

W810821--Figure W1. Hand-sampled. A flash flood occurred while crew was repairing the flume. The samples contained the highest concentration of TS and TDS among the series. The event took place after a long stretch of hot summer days. Salt load associated with this event is estimated at more than 47.2 tons. Initial flushing of the salt crust is evident from the early peak of TDS and TDS/TS ratio. Average TDS and TS concentrations are very high, reading 7682 mg/l and 267684 mg/l respectively.

W810905--Figure W2. Hand-sampled. Discharge, TS and TDS peaked simultaneously but not the corresponding values for TDS/TS. The increase in TDS is correlated to sediment load, an indication that overland flow is a dominant salt delivery mechanism. The initial portion of the hydrograph was not sampled, total loads of salt and TS can not be estimated for the whole event. Average TDS and TS concentrations are 2177 mg/l and 59292 mg/l respectively.

W811003--Figure W3. Hand-sampled. TDS peaked early upon the initial rise in streamflow, then stablized at a constant value. Two episodes of simultaneous peaking of TS and discharge result in two separate rises in TDS and TDS/TS, possibly suggesting channel solute pick-up from two different channels. Samples are supersaturated with gypsum and calcite. Average TDS and TS are 5495 and 132108 mg/l recpectively.

W811011am--Figure W4. ISCO sampler did not switch on properly.

W811011--Figure W5. Hand-sampled. This event took place 5 hours after the preceding one. Average TDS and TS are 1616 and 67158 mg/l respectively. No initial peak in TDS and TDS/TS observed. TDS and TS stay at a fairly constant level throughout the event. Samples are saturated with gypsum and calcite.

W811016--Figure W6. ISCO sampled. The machine missed the first few sampling points. Therefore, important insights into channel solute pick-up are not available. The average TDS is computed to be 1365 mg/l, and average TS is 38414 mg/l.

W811017--Figure W7. ISCO and hand-sampled. Six inches of snow was recorded in Price between the 16th and the 17th of October. Runoff was the result of snowmelt. Since the intake of ISCO sampler is located 11 inches above the floor of the flume and the grab samples are somewhat depth integrated, we see consistent higher TS values for grab samples. A slight increase in TDS and TDS/TS prior to peak discharge suggests some channel solute pick-up, possibly from the lower banks. Average TDS concentration is computed at 1391 mg/l and average TS concentration was 19699.

4.2.2 Interpretation of Results

The following interpretation of results makes frequent reference to Table 5 and Figures W1 through W7. The discussions are directed toward the 7 questions posed in the preceeding section. In the interpretation of results, the process of sediment aggradation and degradation is ignored for lack of actual data. Another important factor not included in the interpretation is mass wasting.

Precipitation - Runoff Relationships

Precipitation and runoff are closly related. Based on information on lines (1) and (9) of Table 5, a linear regression was obtained:

$$RO(in) = 0.00677 * P(in) + 0.1102$$

with a correlation coefficient $r = 0.89$ ($r^2 = 0.79$)

The mean CN value is 94.40 and the standard deviation is 3.63. Both CN and the linear regression can be used equally well to represent the P-RO relation, provided enough significant digits are used to express CN.

TS Load and Runoff

TS load is poorly correlated to RO. This is made clear in Figure 10 where the scatter of data is too much to warrant further analysis. This is also evident from the wide range of values for average TS concentration which is the ratio TS-load/RO. However, if the average TS are examined sequentially, (along line (5) of Table 5) it is evident that there is a declining trend in average TS. Note that event W810905 should be excluded from the discussion, because the initial part of the hydrograph was not available. No defensible explanation for this trend is available at this time. It could be coincidental, since erosive force is more related to kinetic energy of a rainfall (intensity), than to the total precipitation (or, in turn, to the total runoff). It could also represent a seasonal flushing of available salts from source areas.

TDS and Runoff

There is no clear relationship between TDS and RO as shown by the wide range of average TDS values on line (4) of Table 5.

Salt:Solid Ratio

Both the instantaneous ratio and the average ratio of

salt/solid are used here. The average ratios are fairly uniform as shown on line 4 of Table 5. It has a mean value of 3.34% with a standard deviation of 0.69, excluding event CW811017. The 3.34% is close enough to the cited mean of 2% for soluble minerals of hillslope soils to suggest that the salt load is very much dependent on the sediment load from hillslope erosion. The peaking of TDS concentration in TDS-graphs sometimes is associated with peaking of TS. In order to see if TDS and TS both increase in proportion, instantaneous values of TDS/TS ratio are computed and plotted. If an increase in TDS is strictly from the increase in TS, the ratio TDS/TS should remain farily constant. If the ratio increases drastically in the presence of relatively high rate of flow, the increase is then associated with solute pick-up along the channel.

The instantaneous values of TDS and TDS/TS shown in the TDS-, and TDS/TS-graph reveal that the high rate of solute pick-up is mostly associated with the initial phase of the storm (Figure W1). This indicates the occurrence of an initial flushing of channel salts.

Soil Loss Estimates

The actual total solid measured and the USLE-estimated (see Appendix C.2) soil loss are listed below for comparison:

	W811011	W811016	W811017
TS, tons	226	601	183
ULSE estimates	455	530	666

Recalling that the last event was a snowmelt runoff(and should be treated differently), the results of USLE estimates seem to be reasonable.

Overland and Channel Solute Pick-up

If the solute pick-up is strictly related to overland flow erosion, the TDS-load/TS-load ratio should be close to the percentage content of the soluble minerals in eroded soils. Average salt:solid ratio as listed on line 4 of Table 5 would indicate that all the storm events exceeded the 1.99% average cited in (5). Except for event W811017, the percentage figures are however, too close to draw definite conclusions from the average TDS/TS ratio alone.

To further explore the subject, an estimate of in-channel solute pick-up is performed for event W811003 (Figure W3) as follows:

Assume that the TDS from time 1320 to 1350 is the mixture of solute pick-up from both eroded sediment and in-channel dissolution of salt crust. Also assume that a 2% soluble mineral content for eroded soils. The TS load during the period 1320 to 1350 is estimated from integration of Q*TS; the estimate is 235 tons. This amount of sediment should contain 2% salt or 4.72 tons. On the other hand, integration of TDS*Q during the stated period yields 13.0 tons of TDS load. The difference, 8.28 tons (13.0-4.72), should then be the estimated solute pick-up from the channel. The total tonnage of TDS for the event is 19.6, therefore, the estimated solute pick-up from the channel is about 42%. A similar computation using a 4% soluble mineral content would yield estimated channel pick-up at 3.56 tons or 18.2 %.

Similar computations for event W810821 are also performed assuming the first 30 minutes to be the active period of channel solute pick-up. Assigning two different, 2% and 4%, soluble mineral contents to the eroded soils, the estimated solute pick-ups from channel are 7.77 and 2.68 tons respectively. Note that the overall TDS/TS ratio is only 2.87%, and the 4% soluble mineral content is an overestimate for this case. Using 2.87%, the computaion would give 5.56 tons of salt from channel pick-up.

Event W811011, however, indicates very little contribution from channel pick-up due to flushing event W811011 am. Other events do not have complete enough data for channel pick-up computation.

Channel solute pick-up, as expected, is dependent on the time to the preceding storm. Enough time must be allowed for new salt crust to mature before the next runoff event takes place. Event W811011 indicates very little contribution from channel pick-up due to flushing event W811011am occurred five hours ago. Once matured, the salt crust will yield a more or less set amount of salt. This amout is related to the exposure of Mancos Shale in and around the channel only. Thus the preceding computations suggest that a range of 4 to 8 tons of salt may be picked up from the channel of Wattis drainage for a thunderstorm after a long enough dry spell independent of the overland flow process.

Snowmelt Runoff

Event W8011017 is the only snowmelt runoff monitored in this study. It has the lowest sediment load, yet it has the highest salt:solid ratio, 7.05%, roughly doubling the ratios for all other events. Snowmelt does not provide as much kinetic energy as raindrops, hence it has less erosive force. However, snowmelt water has more time to percolate through soils and may result in the leaching of at least as much salt as would be mobilized by a comparable rainstorm.

Mineral Saturation

All the events monitored show saturation with respect to gypsum and oversaturation with respect to calcite. The implication here is that the salt load as computed according to the EC values does not reveal the true dissolution potential of minerals in each of the storm event. Laronne and Schumm (5) showed that the true potential could be as high as 500% of the apparent potential. Apparently, more in-depth study is necessary to verify Laronne and Schumms results on a basin-wide scale.

4.3 Results/Soldier Creek Tributary

None of the soils in this drainage are known to be saline (see Table 3 on page 11). However, there exist numerous deeply dissected gullies exposing saline shales. The depth of gully walls ranges from 20 feet to 40 feet. Runoff and the eroded materials from the gullies undoubtly are the major source of salinity from this drainage.

Mass wasting is another major source of sediment and salinity. The feature of mass wasting was first suspected from a comparison of USLE estimated soil loss and actual tonnage measured. It was later confirmed in a field reconnaissance. A color slide showing a massive amount of sloughing is included in the aperture card (see attached Plate 1).

TABLE 6: SOLDIER CREEK STORM SUMMARY

	Storm	S811003	S811004	S811011	S811013	S811015	S811016
(1)	Runoff volume, A-F	4.77	0.082	4.45	2.46	5.06	8.01
(2)	TDS load, tons	10.0	0.2	4.82	3.32	7.95	NA
(3)	TS load, tons	423	0.96	96	35	249	NA
(4)	Average salt: Solid ratio, %	2.36	20.83	5.02	9.47	3.20	NA
(5)	Average TDS, mg/l	1564	1776	808	1244	1154	NA
(6)	Average TS, mg/l	65531	8621	15853	13142	38414	NA
(7)	Soil Loss, (USLE), tons	NA	NA	27.2	18.1	82	36
(8)	Precipitation, in	0.40	0.20	.26	.15	.4	.65
(9)	Runoff/Precip ratio(Source area)	0.385	0.0126	0.50	0.42	0.41	0.40
(10)	CN (Source Area)	96.46	92.83	98.35	98.78	96.71	94.61
(11)	Runoff/Precip ratio(whole area)	0.179	0.006	0.25	0.295	0.29	0.285
(12)	CN (Whole area)	93.52	92.26	96.55	98.23	95.36	92.56
(13)	Comments:	C	C	C	C	C	MF
(14)	Methods of Sampling	M	M	ISCO	ISCO	ISCO	ISCO

Notes: C = Complete hydrograph sampled
MF = Records for initial part of storm event not available
NA = Not available

4.3.1 Description of Storm Events

S811003--Figure S1. Hand-sampled. Peak portion discharge was estimated within three inches of a staff gage. TDS peaked early upon the rising limb of the hydrograph and flushing action is obvious although quantity could be very small. TDS and TS averaged 1564 and 65531 mg/l respectively. Samples show saturation with respect to gypsum and calcite.

S811004--Figure S2. Hand-sampled. No obvious flushing is observed. A rise in TDS occurred late in the recession limb of the hydrograph. Samples at the recession limb show saturation with respect to gypsum. TDS and TS average 1776 and 8621 mg/l respectively.

S811011--Figure S3. ISCO sampled. TDS is higher in the initial part of the event and at 808 mg/l over the duration of flow. Average TS is 15853 mg/l.

S811013--Figure S4. ISCO sampled. Peaking of TDS and TDS/TS occurred on the rising limb of the hydrograph, giving evidence of channel solute pick-up. TDS and TS averaged at 1244 and 13142 mg/l respectively. Samples are saturated with calcite but undersaturated with respect to gypsum.

S811015--Figure S5. ISCO sampled. Sampling resolution was poor. Average TDS and TS are estimated at 1154 and 38414 mg/l respectively. Samples are saturated with respect to calcite but not with respect to gypsum.

S811016--Figure S6. ISCO sampled. Sampler did not switch on properly. No load computations were performed. Samples are saturated with respect to calcite, but not to gypsum.

4.3.2 Interpretation of Results

The gage site was selected because it was a convenient hydraulic control. A computation of normal depths and critical depths along the culvert and the leading channel reveals that the culvert is hydraulically steep and the entry section of the culvert is a critical section. The slope of the culvert is 0.0237; the value of Manning's n is estimated at 0.024 for the 8' corrugated culvert. The n value was suggested in the Handbook of Steel Drainage and Highway Construction Products published by American Iron and Steel Institute in 1971.

The water level at the gage is practically equal to the total head and is about 1.5 times the critical depth at the entry of the culvert. Thus the rating curve for the gage is obtained from

a critical depth computation at the culvert.

Precipitation - Runoff Relationships

There is no obvious systematic relationship between precipitation and runoff judging from an examination of lines (1), (8), (9), and (10) of Table 6. Since the precipitation records were collected at only one point in the basin, the precipitation data is hardly representative of the whole basin. Thus, no rational relationships are sought here.

TS Load (or TDS Load) and Runoff

As is obvious from lines (5) or (6) of Table 6, little systematic relation between TDS load or TS load and runoff is expected. A similar situation was observed in Wattis drainage and was discussed in Section 4.2.2.

Salt: Solid Ratio

The instantaneous values of TDS/TS show a wide range of fluctuations as depicted in Figures S1 through S6; some of the ratios reach as high as 50%. This is due to either of two reasons: (1) at low flow rate, sediments readily deposit along the channel leaving a lower proportion of total solids, or (2) when there are sufficient flows to transport sediments in suspension, the high ratio reflects solute pick-up from more concentrated sources such as salt crusts along the channel. The event S811004 in which the peak discharge is only 1.5 cfs, appears to be a case of the former.

Line (4) of Table 6 shows a wide variation of salt to solid ratio. The variation is attributed to the different degrees of solute pick-up from the channel. Storm S811004 has very low runoff volume and the salt to solid ratio is as high as 20 percent.

On the other hand, the overall discharge-average (for 5 samples) salt to solid ratio is comparable to values at Wattis drainage, 3.58% as shown in Table 9 in section 4.6. The corresponding ratio in the Wattis drainage was 3.43% (Table 9).

Soil Loss Estimates

The measured total solids and the USLE-estimated (see Appendix C.2) soil losses are listed below:

	S811011	S811013	S811015
TS, tons	96	35	249
USLE estimates	27.2	18.1	82

It is obvious that USLE estimates are consistently lower than the measured loads. A field trip was arranged specifically to explore possible reasons for this discrepancy.

During the field trip, notable mass wasting was found along the main stem of the drainage. At about 0.5 miles upstream from the gage site, massive sloughing created a temporary dike across the channel and a large pond behind the dike (See attached plate 1). There is no doubt that mass wasting must play an important role in this drainage. The quantity of mass wasting was not estimated, but it should account for part of the discrepancy between the measured TS load and USLE-estimated soil erosion.

Overland and Channel Solute Pick-up

Unfortunately, the resolution of the sampling on all the six hydrographs is not fine enough to warrant a computation of channel solute pick-up. In view of the massive sloughing observed, the TDS-graph and TS-graph should have some patterns different from that associated with simple salt pick-up from the channel. The salinity impact of sloughing on runoff should be a subject for future investigations.

Mineral Saturation

Conditions of mineral saturation monitored at this site are similar to those at the Wattis drainage. All samples show saturation with respect to Calcite; saturation level of Gypsum, however, is not as high.

4.4 Results/Coal Creek Tributary

The erodible soils in this drainage are mostly colluvium, not saline. No exposed Mancos Shales exist along the drainage channels. Therefore, source materials are not likely to produce excessive amounts of salinity.

The lowland areas are contour furrowed and consist of some gullies. The gullies are about 10 feet deep. These furrowed areas are relatively flat and expected to produce little runoff. The furrows along the foothills and around gullies can provide runoff control. The effect of these furrows on runoff is not known. It would appear that they could slow down the advancement of the gullying process at least.

Since the source materials are not saline, it is not a salinity hazard area, a fact reflected in our results. This is the smallest watershed studied. The drainage channels are not as well developed or dissected except in the lower drainage. There is little evidence of solute pick-up from the channel. Most of the TDS and TS appear to be related to the overland flow processes or possibly some mass wasting. Five sampled events are described below; (refer to Figures C1 through C5 and Table 7 for summary of events):

TABLE 7: COAL CREEK STORM SUMMARY

	Storm	C811003	C811004	C811012	C811013	C811016
(1)	Runoff volume, A-F	0.09181	0.01653	0.861	0.8430	1.638
(2)	TDS load, tons	0.0430	0.004065	0.254	0.30	0.46
(3)	TS load, tons	28.8	0.0625	6.69	10.6	16.7
(4)	Average salt: Solid ratio, %	1.49	6.5	3.80	2.83	2.75
(5)	Average TDS, mg/l	380	181	218	262	207
(6)	Average TS, mg/l	19800	2783	5715	9218	5709
(7)	Soil Loss, (USLE), tons	NA	NA	11.5	2.4	14
(8)	Precipitation, in	.2	.4	.65	.3	.75
(9)	Runoff/Precip ratio (Source area)	.051	.0045	.146	.310	.241
(10)	CN	94.46	85.34	88.79	96.68	90.40
(11)	Runoff/Precip ratio (whole area)	0.0133	0.0012	0.0385	0.0816	0.063
(12)	CN	92.87	84.39	82.97	92.97	82.88
(13)	Comments:	C	C	C	C	C
(14)	Method of Sampling	M	M	ISCO	ISCO	ISCO
(15)	Channel Solute pick-up	0	0	0	0	0

Notes: C = Complete hydrograph sampled
MF = Records for initial part of storm event not available
NA = Not available

4.4.1 Description of Storm Events

C811003--Figure C1. Hand-sampled. No large peaks of TDS and TDS/TS. Average TDS is computed at 380 mg/l, and TS at 19800 mg/l. TDS/TS ratios rise along the recession limb of the hydrograph, possibly indicating the deposition of sediments due to low levels of flow.

C811004--Figure C2. Hand-sampled. No large peaks of TDS and TDS/TS. Average TDS is 181 mg/l. Average TS is estimated at 2783 mg/l. At low flows, TDS/TS shows higher value. Samples are supersaturated with respect to calcite, and very much undersaturated with respect to gypsum.

C811011--Figure C3. ISCO sampled. TDS remains at a fairly constant value. Average TDS and TS are 218 and 5715 mg/l respectively. Samples are saturated with respect to calcite and very much undersaturated with respect to gypsum.

C811013--Figure C4. ISCO sampled. Values of TDS remain at a fairly constant value. Average TDS and TS are 262 and 9218 mg/l respectively.

C811016--Figure C5. ISCO sampled. TDS and TS peak early upon rise in stream flow but remain very moderate in magnitude later upon the recession limb. The early peaking of TDS and TS is not accompanied by a peak in TDS/TS ratio, suggesting the predominance of overland erosion and solute pick-up, as opposed to channel solute pick-up.

4.4.2 Interpretation of Results

The water quality of all the storm runoff events in this watershed is good. Average TDS concentration ranges from 180 mg/l to 380 mg/l. Instantaneous high TDS values seldom reach beyond 400 mg/l. Average TS concentration is also very low ranging from 2783 to 19800 mg/l. The high intantaneous TS values rarely go above 35000 mg/l.

Precipitation and Runoff

The events according to RO/P ratio can be separated into two distinct groups: (1) very low ratios for C811003 and C811004, and (2) the rest of the events having ratios averaging about 0.30. Apparently there is little consistency considering the five events as a set. No attempt is made to find a formal relation between P and RO. It should be noted that the one rain gage is located in the middle of the watershed where not much runoff is anticipated and the suspected runoff source areas are west of the

gage. The spatial variation of precipitation may be one reason for the large differences in RO/P ratios.

It is of interest to note that for storm events C811011, C811013, and C811016, the RO/P ratios are comparable to those recorded in Badger Wash, Colorado (Lusby et al, 6), where an average ratio of 0.32 with 0.02 standard deviation was reported for watersheds with 40-acre catchment. Notice that this RO/P ratio is high compared to the set of values for the events in the Wattis watershed, likely due to larger size of the Wattis catchment basin.

Salt/Solid Ratio

Except for the extremely low flow events, C811003 and C811004, the average salt/solid ratio has a mean value of 3.13% with a standard deviation of 0.48. The mean value appears to be reasonable for Mancos Shale derived soils. Salt load can be predicted from sediment load.

TDS/TS-graphs show very little peaking. Event C811013 shows a peaking at time 1812. This could very well be associated with the low flow rate. Event C811016 shows initial peaking of TDS and TS, but the TDS1TS ratio remains almost a constant indicating the observed peaking of TDS is related to overland flow process, instead of in-channel process.

Overland and Channel Solute Pick-up

There is little evidence of solute pick-up from the channels.

Soil Loss Estimates

Actual soil loss and the corresponding estimates from USLE (see Appendix C.2) in tons are listed below:

	C811011	C811013	C811016
Actual load	6.69	10.6	16.7
USLE estimate	1.7	2.8	14.0

Considering the many uncertainties e.g. guantity of mass wasting, in the participating parameters, the USLE estimates seem to be reasonable. The accuracy can be improved if the precipitation stations are placed close to runoff source areas, and better estimates of other USLE factors are obtained and mass wastings are quantified.

Mineral Saturation

The chemical analysis of the selected samples shows that all the tested samples are calcite-saturated. However, they are undersaturated with respect to gypsum as shown in Figures C1 through C5.

4.5 Results/Grassy Trail Creek Drainage

Two events were sampled during the study. Table 8 gives a summary of the two events.

Table 8: GRASSY TRAIL CREEK STORM SUMMARY

	Storm	G811003	G811017
(1)	Flow volume, A-F	171	374.5
(2)	TDS load, tons	>218	>359.4
(3)	TS load, tons	>19193	>8254
(4)	Average salt: Solid ratio, %	1.14	4.35
(5)	Average TDS, mg/l	932	706
(6)	Average TS, mg/l	82161	16218

4.5.1 Description of Storm Events

G811003--Figure G1. Hand-sampled. TDS remains fairly constant after peaking during the first hour of the event. Figure G1 shows only the first part of the hydrograph. Discharge, TDS and TS remain fairly constant after hour 0300. The last point sampled was at 1315 of October 4. At that time the discharge was high. Average TDS for the time span monitored is 932 mg/l and average TS is 19193. The first hour peak of TDS/TS suggests channel solute pick-up. Samples are saturated with respect to calcite but not gypsum.

G811017--Figure G2. ISCO sampled. The event was preceded by a series of unsampled runoff events on October 12 and 13. The duration of this event is about three days. Initial high values of TDS are observed. TDS tends to stablize at a constant value around 500 mg/l. Average TDS and TS are 359 and 8254 mg/l respectively. Samples show saturation with respect to calcite but not gypsum.

4.5.2 Interpretation of Results

Overland and In-channel Solute Pick-up

For event G811003, channel solute pick-up computation is performed as follows: Assume active channel pick-up occurred from time 2000 to 2120. Also assume the soluble mineral content to be 1%, judging from average TDS/TS ratio of 1.14%. During the period 2000 to 2120, the TS load is estimated at 3556 tons, presumably one percent of which is dissolved solid, or 35.56 tons. The TDS load is 45.0 tons for the period. The channel solute pick-up is therefore about 10.0 tons. As noted in Laronne and Schumm (5), bed materials of Grassy Trail Creek mainly consist of well leached fluvial deposits. Therefore the relatively low tonnage in channel pick-up is expected.

4.6 Summary

Statistics of runoff and water quality for the monitored storm events are summarized for each watershed in the following Table 9:

Table 9: Runoff and Water Quality Summary

		Wattis Watershed	Soldier Creek	Coal Creek	Grassy Trail Creek
Area, acres		33130	800	262	185000
Mean slope		14.7%	10.9%	9.93%	NA
Runoff,A-F	Max	11.51	8.01	1.638	374.5
	M(#)	5.70(7)	3.73(6)	0.690(5)	272.8(2)
	Min	2.475	0.04	0.0165	171.0
TDS,(tons)	Max	47.2	7.95	0.46	359.4
	M(#)	19.03(6)	4.24(5)	0.212(5)	288.7(2)
	Min	5.43	0.10	0.00406	218
TS,(tons)	Max	1643	249	28.8	19193
	M(#)	555(6)	118(5)	12.57(5)	13723(2)
	Min	183	0.48	0.0625	8254
Salt/Solid %	Max	7.05	20.83	6.50	4.35
	M(#)	3.43(6)	3.58(5)	1.69	2.10
	Min	2.41	2.36	1.49	1.14
Aver. TDS(mg/l)	Max	7682	1776	380	932
	M(#)	3288(6)	1309(5)	250(5)	819(2)
	Min	1365	808	181	706
Aver. TS(mg/l)	Max	267684	65531	19800	82161
	M(#)	97393(6)	28312(5)	8645(5)	49190(2)
	Min	19699	8621	2783	16218
RO/P*	Max	0.272	0.42	0.310	
	M(#)	0.146(6)	0.32(6)	0.185(5)	NA
	Min	0.089	0.007	0.0045	
Mineral Saturation					
w.r.t. Gypsum		yes	no	no	no
w.r.t. Calcite		yes	yes	yes	yes

Notes for Table 9:
M: Arithematic mean values
#: Number in parenthesis is the number of samples used in calculating the mean.
*: Based on source area

Except in the Wattis watershed, recorded precipitation and runoff are not systematically related. This is due, in part, to insufficient number of rainfall monitoring points. In arid and semi-arid regions, a four-digit curve number is necessary to yield meaningful P-RO relationships.

There is a wide range of variation in average TDS and TS concentrations. Also, there is little relation between runoff volume and TDS load or TS load.

TDS and TS concentrations obtained in this study are generally substantially higher than the results of plot or microwatershed studies. The difference may be attributed to the effect of incline-length of hillslopes, and the erosive power of natural rainfall. Only plots on steep, dissected shale badlands yield TS and TDS values comparable to those observed in this study (Jackson and Julander 3). This indicated that steep, shale badland features may be important sources of sediments and salts.

Average TDS concentrations are more or less proportional to average TS concentrations, and the TDS/TS ratio is comparable to that expected of shale derived soils suggesting water quality is dependent on hillslope erosion. Wattis has the highest average TDS and TS at 3288 and 9739 mg/l respectively and Coal Creek (Tributary) watershed has the lowest at 250 and 8645 mg/l respectively.

Sediment production per unit area varies from watershed to watershed. Sediment load per unit area for Wattis, Coal Creek, and Grassy Trail Creek are respectively 0.168, 0.0304 and 0.00156 tons per acre. Relative differences in sediment loading appear predictable from an erosion analysis using USLE.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The following conclusions may be drawn from this study:

(1) The salt/solid ratios associated with storm runoffs are related to soluable mineral content of erodible soils.

Excluding the snowmelt runoff event, the mean TDS/TS ratios, runoff-weighted, are:

Wattis Watershed	: 3.43%
Soldier Creek	: 3.58%
Coal Creek	: 1.69%
Grassy Trail Creek	: 2.10%

For Mancos Shale areas, such as Wattis and Soldier Creek drainages, a 3.3% (or 1/30) may be a reasonable figure for the prediction of TDS from sediment load. For other less saline areas, one should expect a lower figure.

(2) The relative uniformity of average TDS/TS ratio suggests that TDS concentration is strongly dependent on sediment concentration. Except during active periods of solute pick-up from channel salt crusts, and during periods of low turbulence, the instantaneous value of TDS/TS is only slightly less than the soluble mineral content of the eroded soils.

(3) Overland flow processes are important factors in salt production from wildlands. However, channel solute pick-up could be of equal importance in some drainages for some storms, especially during runoff events preceded by long, dry periods. Little baseflows are observed for the storms monitored.

(4) Reasonable success with USLE appears to be possible. The underlying principles of the USLE are consistent with findings of this and other related studies:

(a) EC (derived from eroded soils) increases as the inclination of hillslope increases.

(b) Erosive power of precipitation is the driving force of erosion process. Therefore total precipitation (hence total discharge) will not necessarily relate systematically with soil loss (or the related EC). If committed to the principles of USLE, one should not expect total discharge or total precipitation to correlate with sediment yield or EC.

(5) USLE predicts a linear relationship between soil loss (hence the associated EC) and the slope length. This is the only apparent contradiction between USLE and results of similar investigations; e.g. Ponce's found that EC is independent of the length of hillslopes.

(6) For a given storm runoff the overland and in-channel components of solute pick-ups can be separated quantitatively, if enough details of the hydrograph, the TDS- and the TS-graphs are collected.

(7) In-channel solute pick-up mainly occurs in the inital phase of the storm event. Instantaneous values of TDS/TS and TDS should be examined simultaneously to confirm the channel solute pick-up process.

(8) A reasonable scenario of in-channel solute pick-up is proposed: given enough time, salt encrustations should reach a mature state. The total quantity of soluble mineral of a matured encrustation for a drainage is more or less a constant. And this constant varies from drainage to drainage depending on how much Mancos Shale is exposed in the channel.

(9) Channel solute pick-up in Wattis watershed is estimated to be a maximum of from 4 tons to 8 tons for matured salt encrustation. This salt pick is about 20% to 40% of the observed salt load of a storm, but this percentage would vary as a function of storm size and sequencing. The corresponding estimates for Grassy Trail Creek and Coal Creek are 10 tons and zero respectively.

(10) Almost all the water samples analyzed for ion species show saturation with respect to calcite, for all the watersheds and with respect to gypsum for Wattis watershed. Quantitative implications of dilution effects on water saturated with minerals are still uncertain.

5.2 Recommendations

For future considerations, the following items are recommended:

(1) Conduct studies to validate the general applicability of USLE in western desert lands for individual storm events. With combined information on soils already available at BLM and SCS, this will only require more monitoring points for recorded rainfall in suspected runoff source areas. Recorded rainfall data give the all important information on the erosive power of rainfalls. SCS' **Soil and Vegetation Inventory Method** (or **SVIM**), in addition to the soil information discussed so far, also gives

nature and coverage of vegetation useful for estimating the factor **C** used in USLE.

(2) Perform infiltration studies for soils of suspected runoff areas. This will improve the capability for runoff prediction.

(3) For planning purposes, USLE could be used to estimate annual sediment load. This can be accomplished by using BLM's soil inventory already available for many areas, and by using the annual rainfall factors already developed by SCS. To predict salt load from sediment load, maybe more comprehensive dissolution potential studies are required in addition to Laronne's work.

(4) To quantify channel solute pick-up, a geochemical study of the surface materials of the lower walls and the bottom of the channels should be carried out. A study is required to clarify the issue of dilution effects on water saturated with gypsum and calcite.

(5) If this study is to repeat again, we recommend using a Stevens type A-35 recorder for Grassy Trail Creek site in order to cover the 2 to 3 day time base of storm events.

(6) Gully plug studies may also benefit by USLE approach. This would require a recording raingage and surveying of changing bottom topography. A field scale computer program, called **CREAMS**, is now avilable and could be tested for field watershed studies. CREAMS is based on USLE and is available from SCS. The program also deals with degradation and aggradation of sediments on hillslopes.

(7) There are still shortcomings associated with automatic sampling. The machine sampling procedures should be designed to switch on in a more predictable fashion. There should be more flexible options of sampling sequence. Before the apparent drawbacks of machines are overcome, hand-sampling still has to be used to enhance the value of machine samples.

APPENDIX A

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Figure S4 - Storm Event S811013
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Figure S6 - Storm Event S811016
Figure C1 - Storm Event C811003
Figure C2 - Storm Event C811004
Figure C3 - Storm Event C811011
Figure C4 - Storm Event C811013
Figure C5 - Storm Event C811016
Figure G1 - Storm Event G811003
Figure G2 - Storm Event G811017

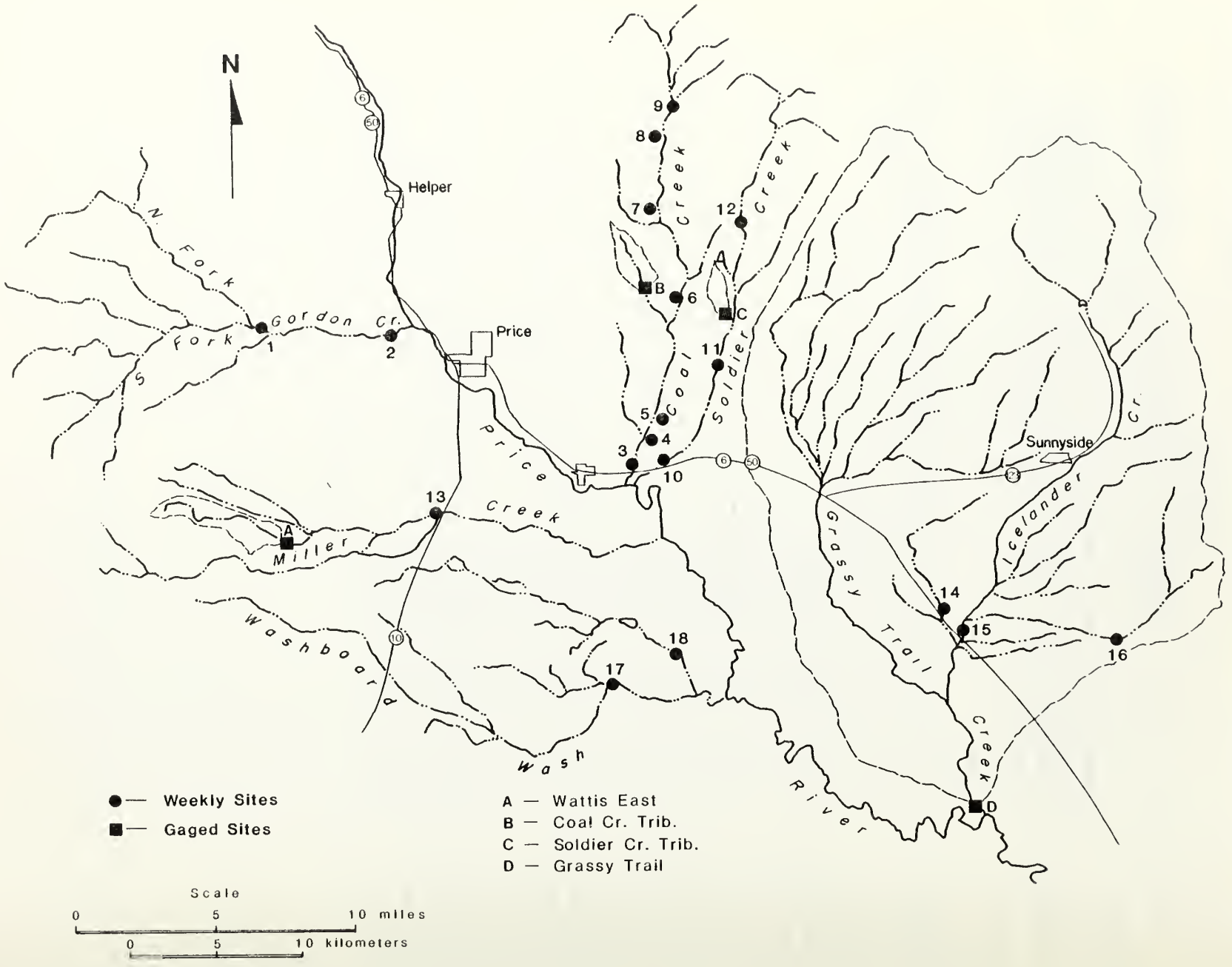


Figure 1.- Map showing study area & sites monitored

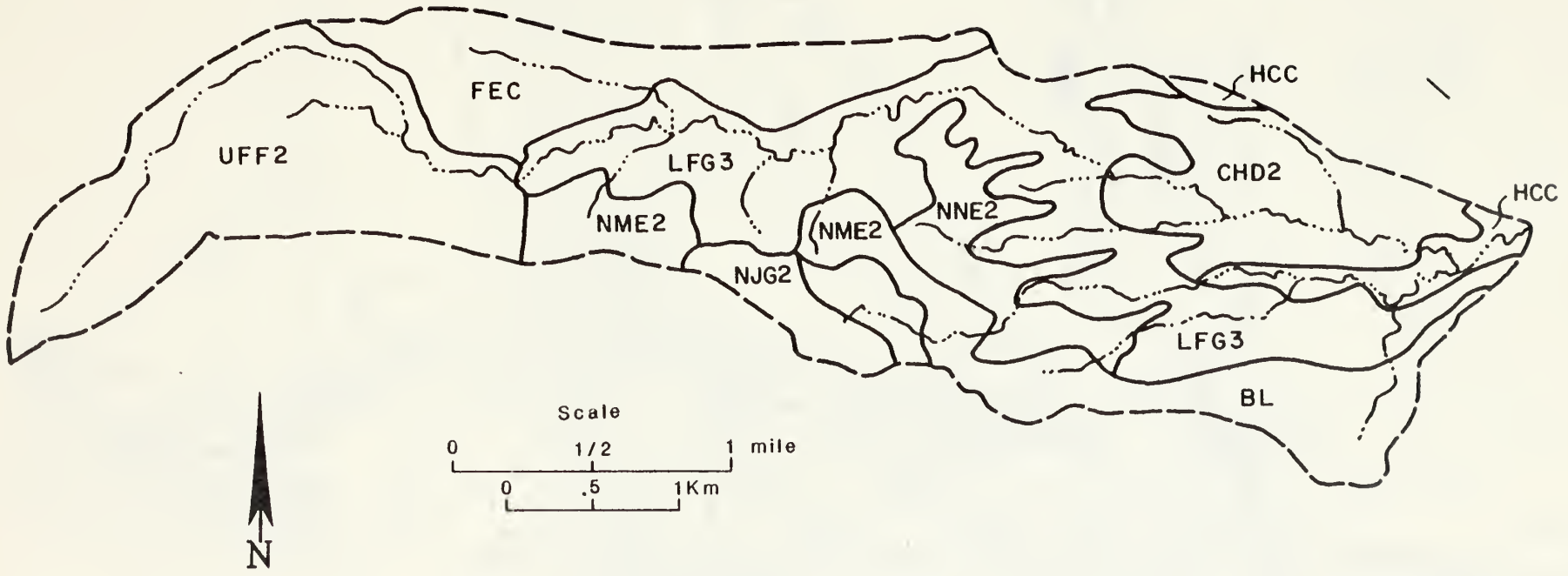


FIGURE 2.- Wattis Drainage, Showing Soil Types and Drainage Channels

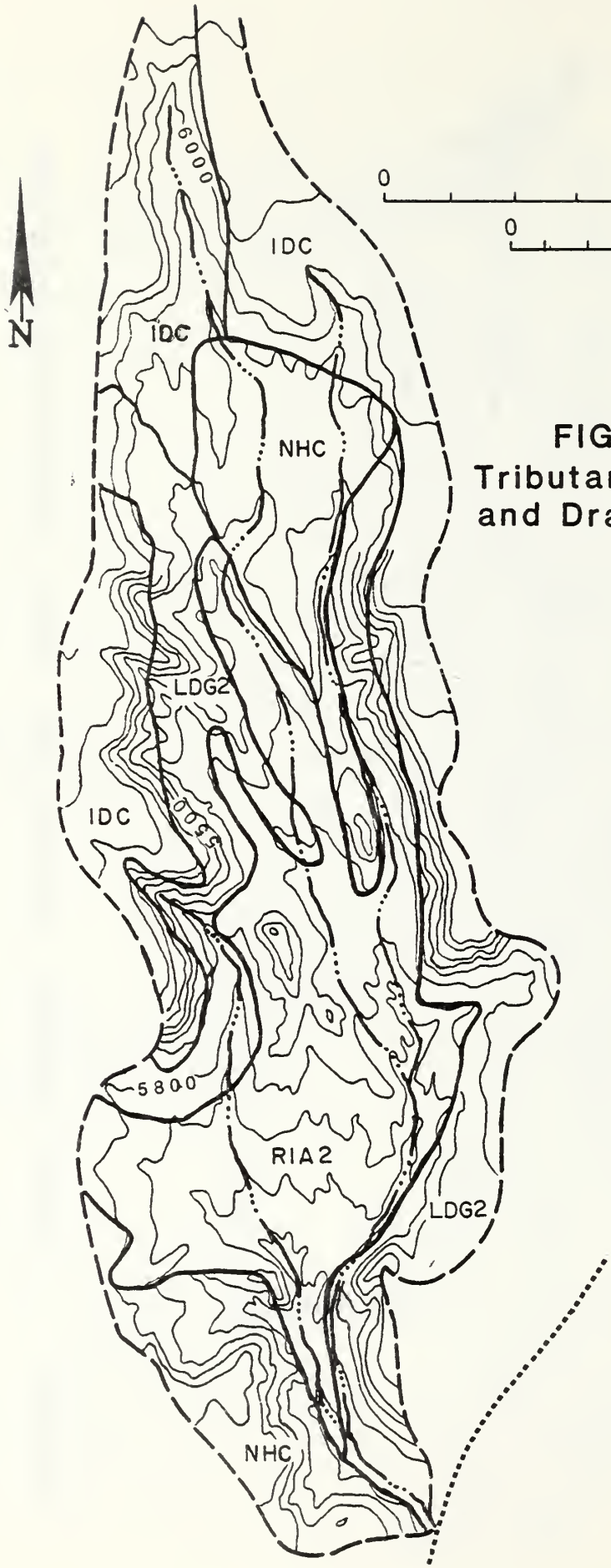
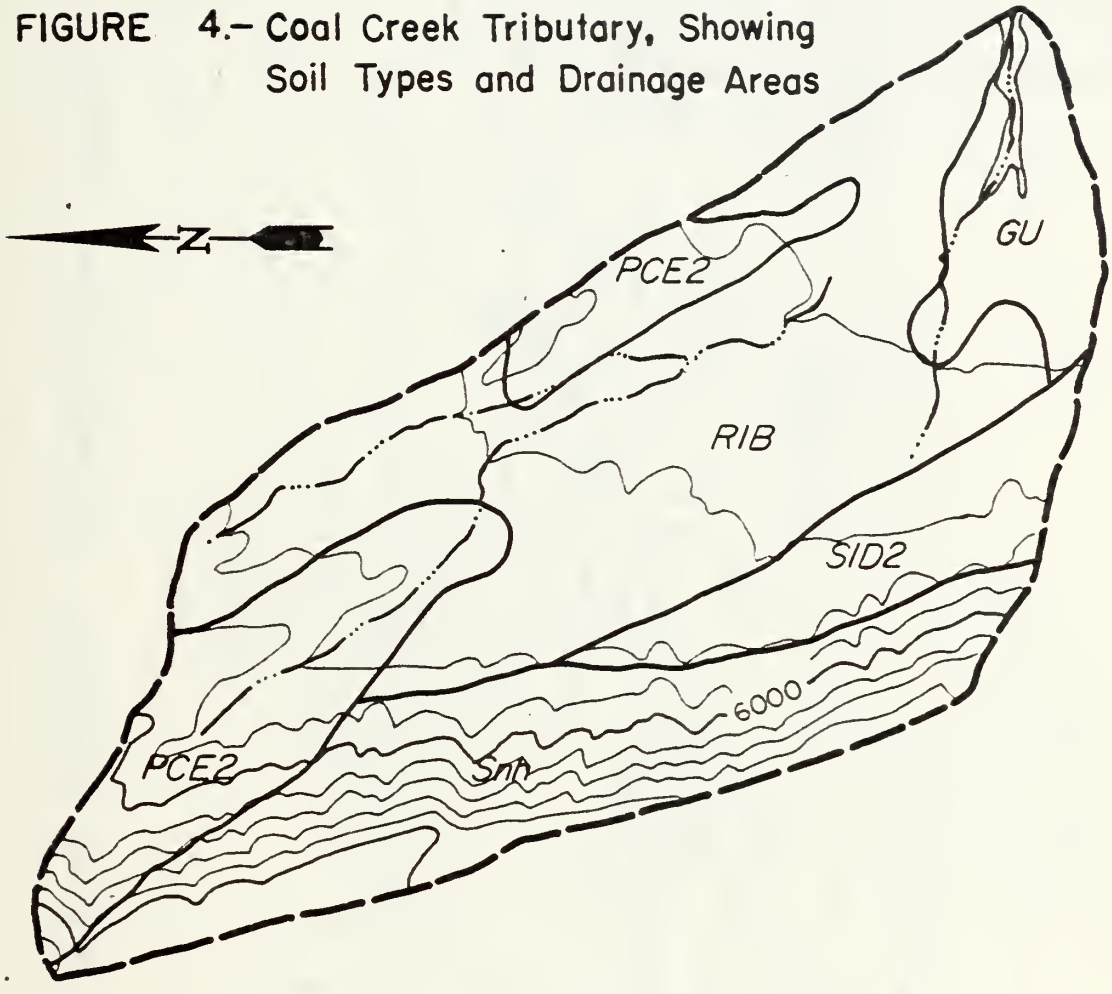


FIGURE 3.- Soldier Creek Tributary, Showing Soil Types and Drainage Channels.

FIGURE 4.– Coal Creek Tributary, Showing Soil Types and Drainage Areas



Scale

0 1/2 1 mile

0 .5 1 kilometer

Contour Interval 20 ft.

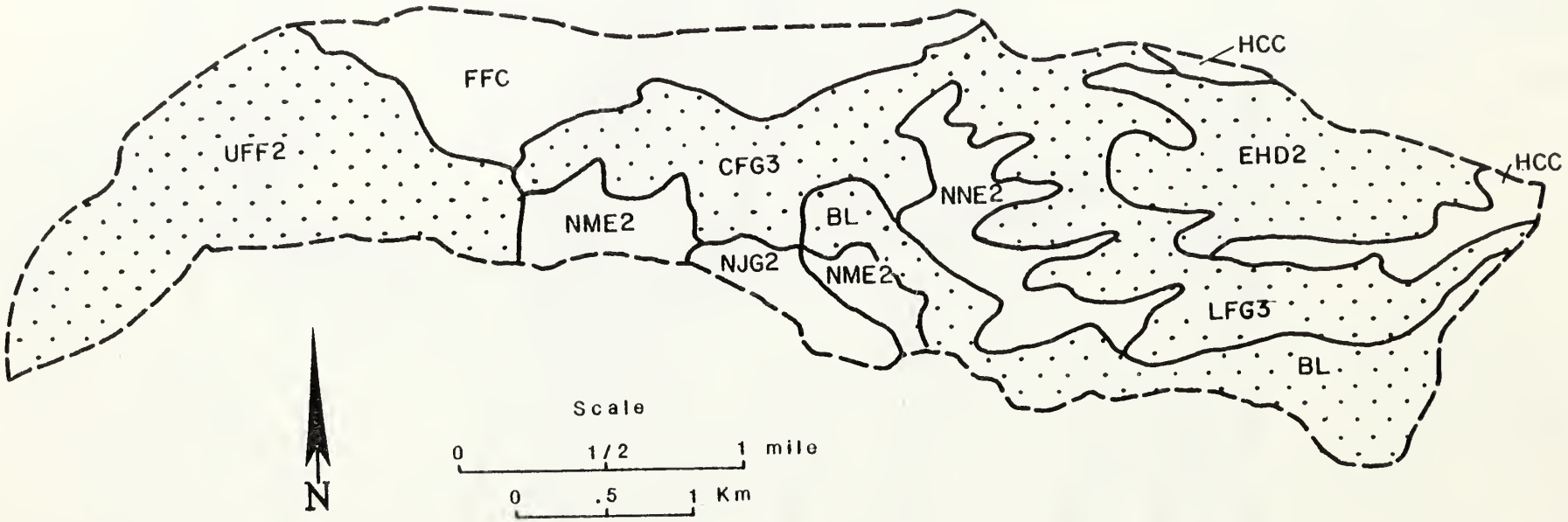


FIGURE 5.- Wattis Drainage , Showing Runoff Source Areas

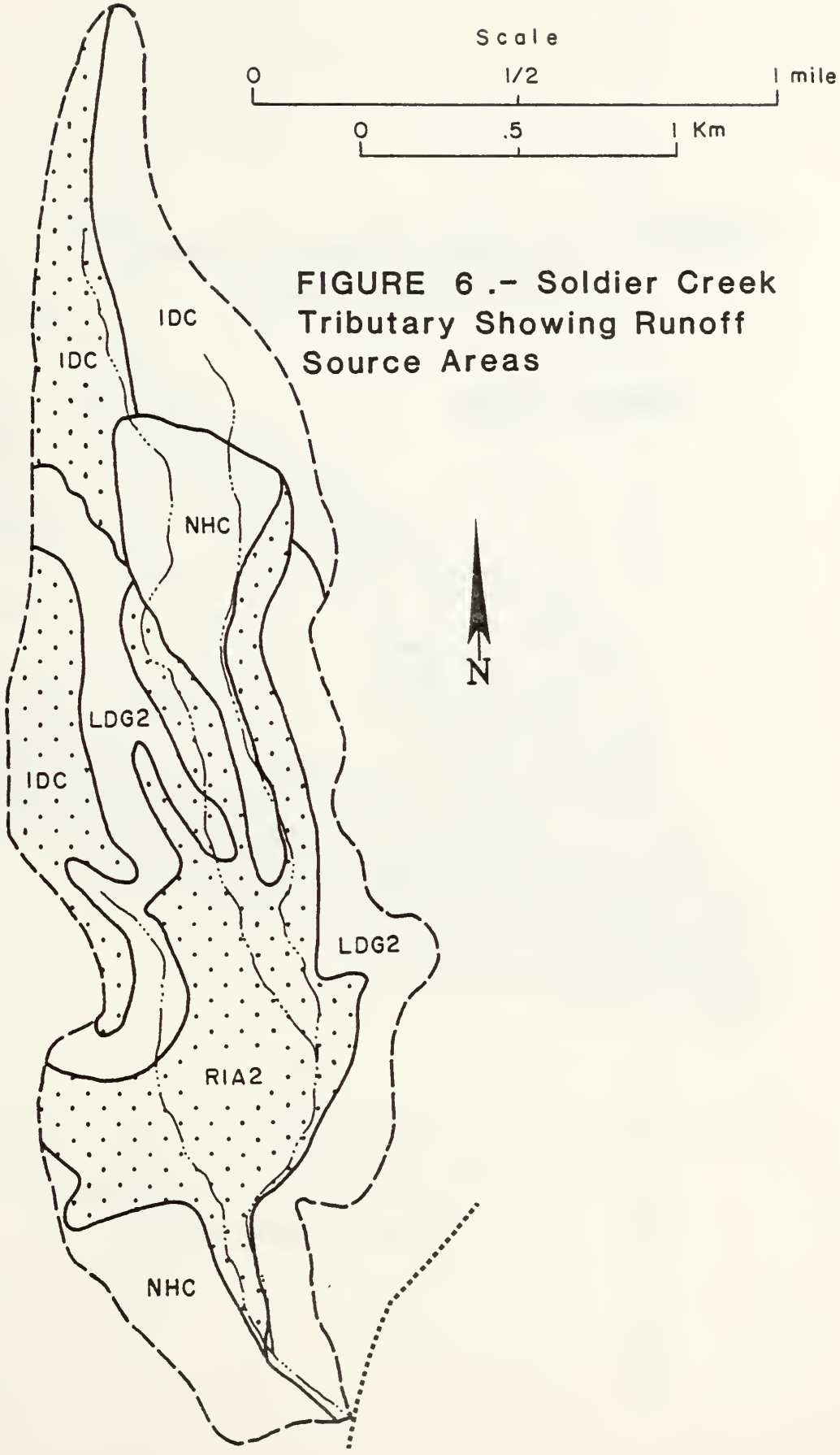
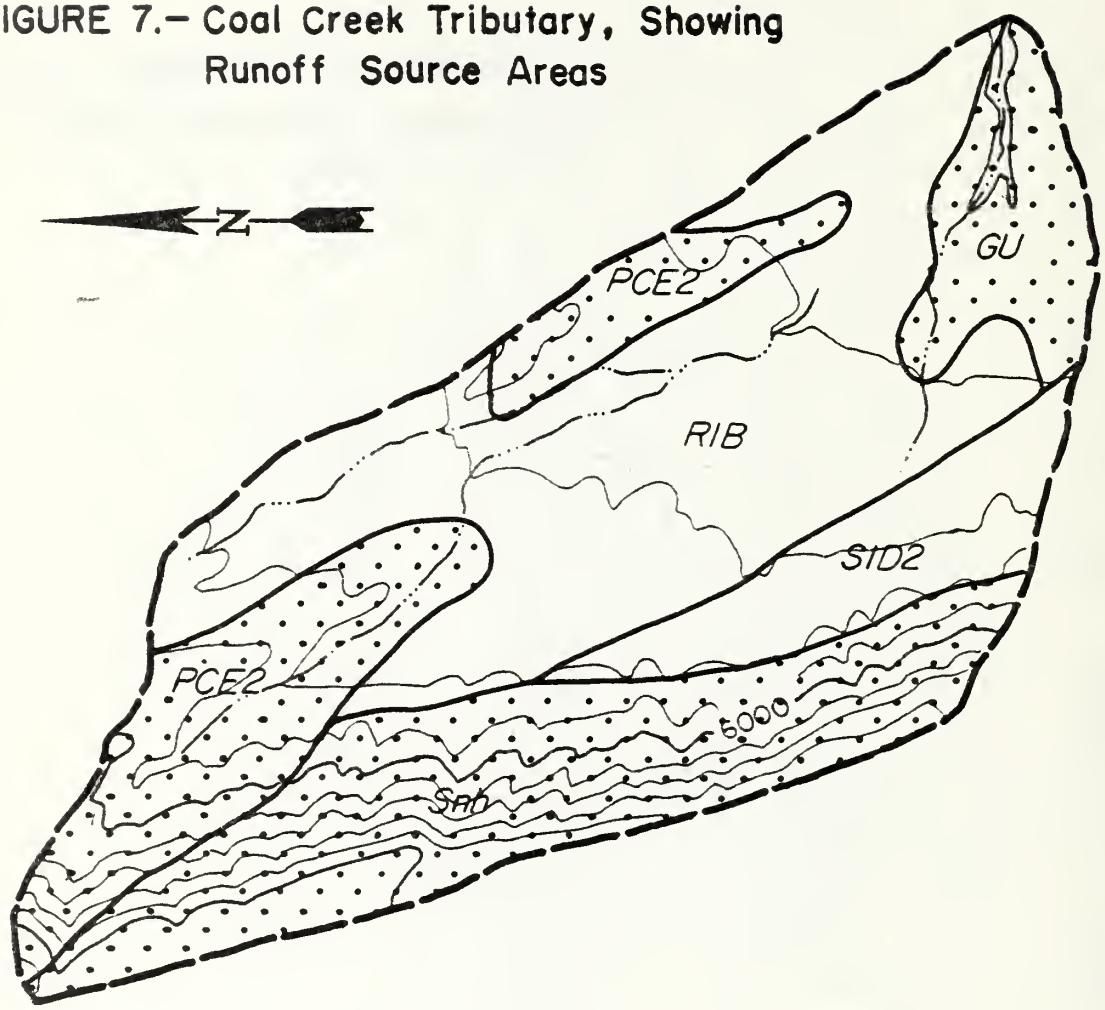


FIGURE 6 .- Soldier Creek Tributary Showing Runoff Source Areas

FIGURE 7.– Coal Creek Tributary, Showing Runoff Source Areas



Scale

0 1/2 1 mile

0 .5 1 kilometer

Contour Interval 20 ft.

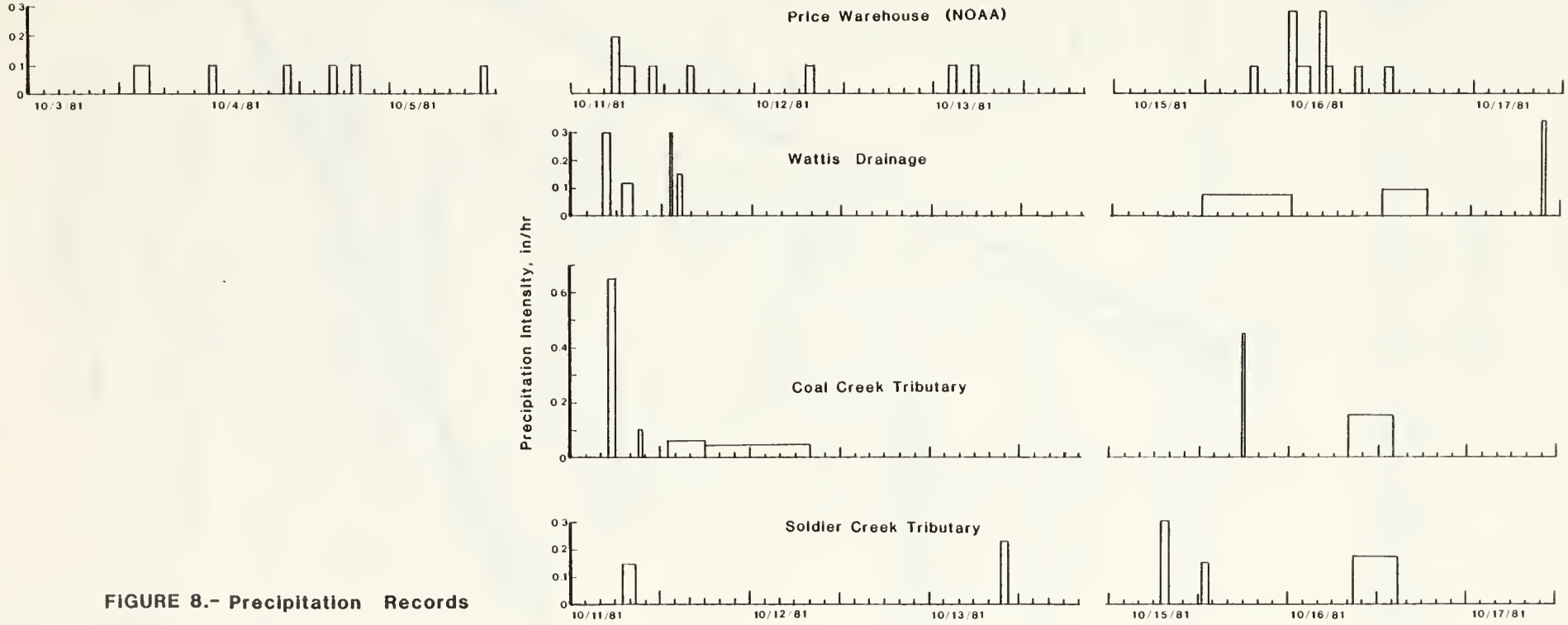


FIGURE 8.- Precipitation Records

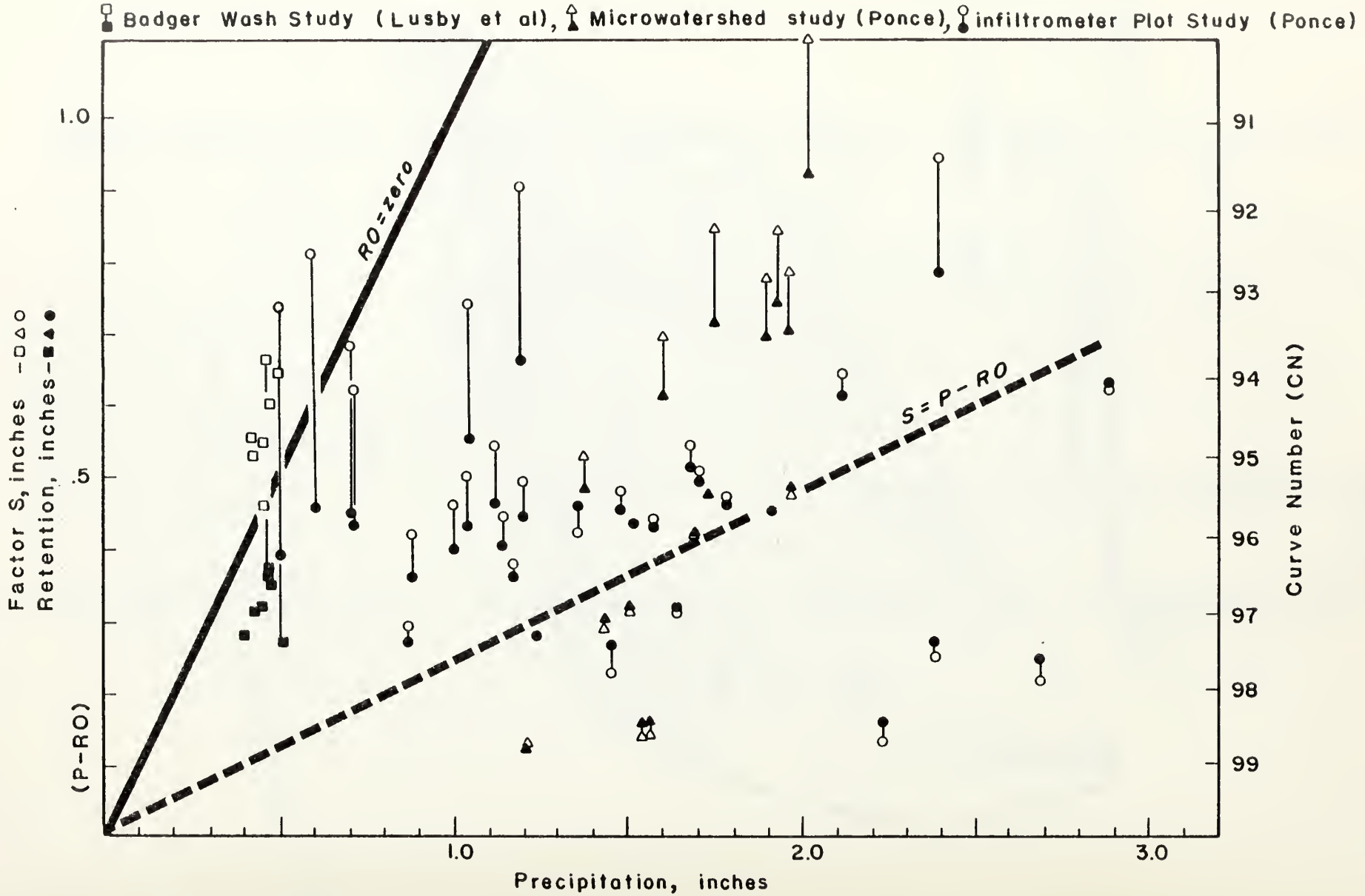
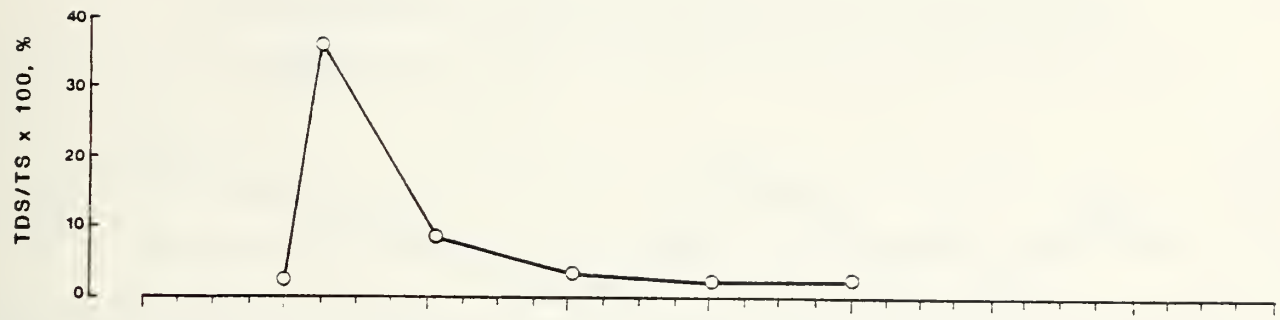


FIGURE 9.- Precipitation, Retention and Curve Numbers



UINTEX

FIGURE W1.- Storm Event W810821

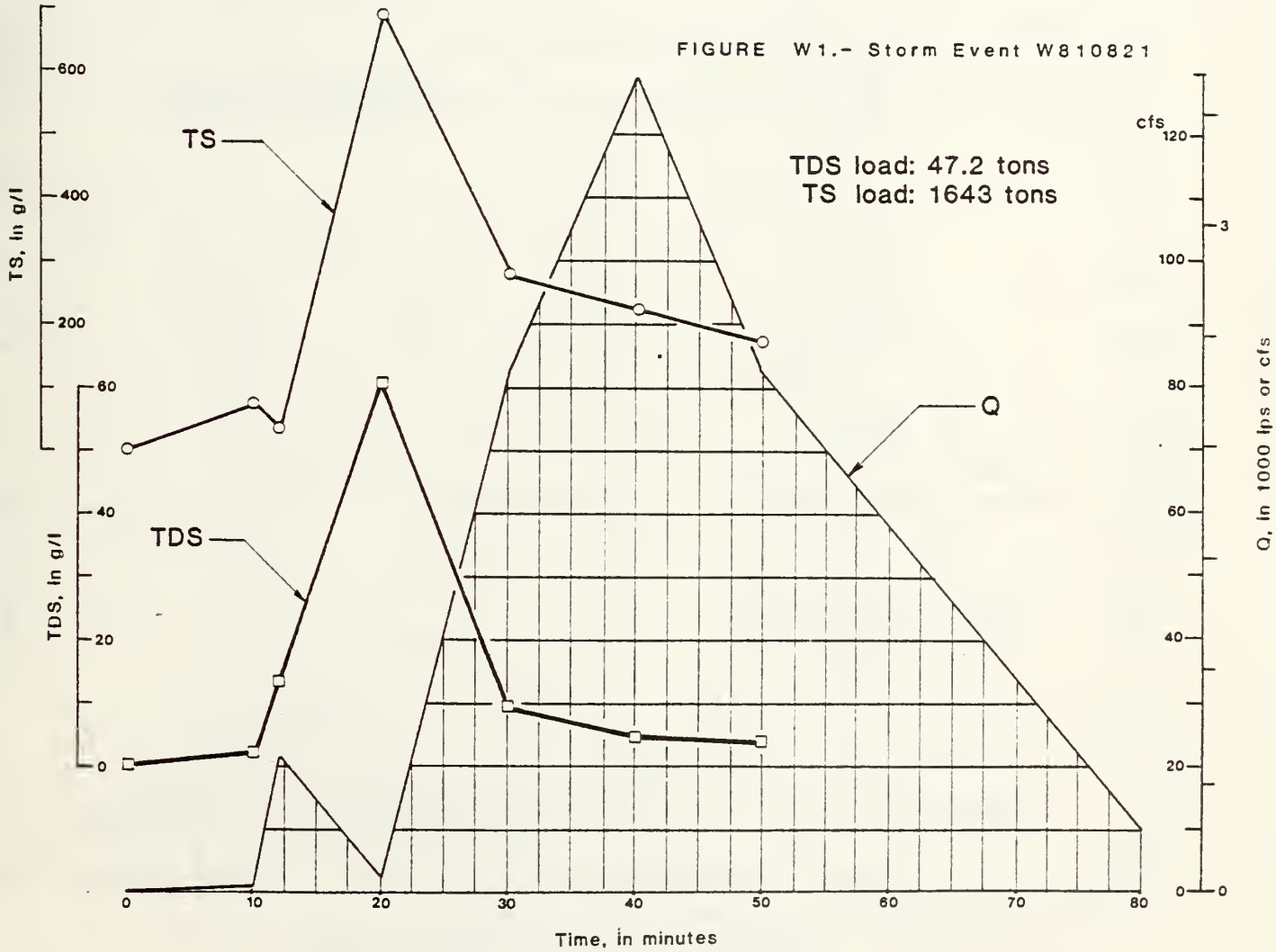


FIGURE W1.- Storm Event W810821

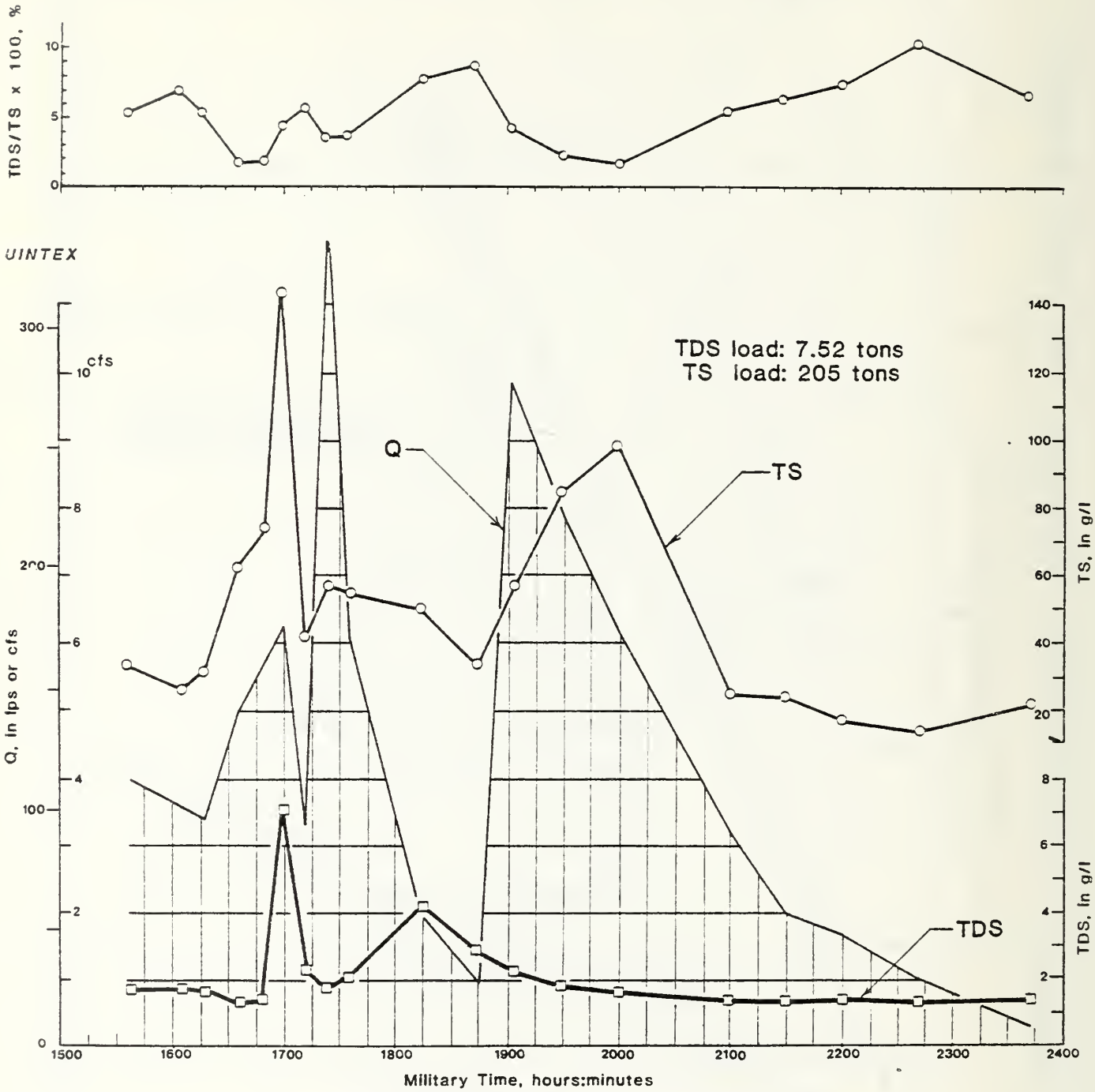


FIGURE W2.- Storm Event W810905

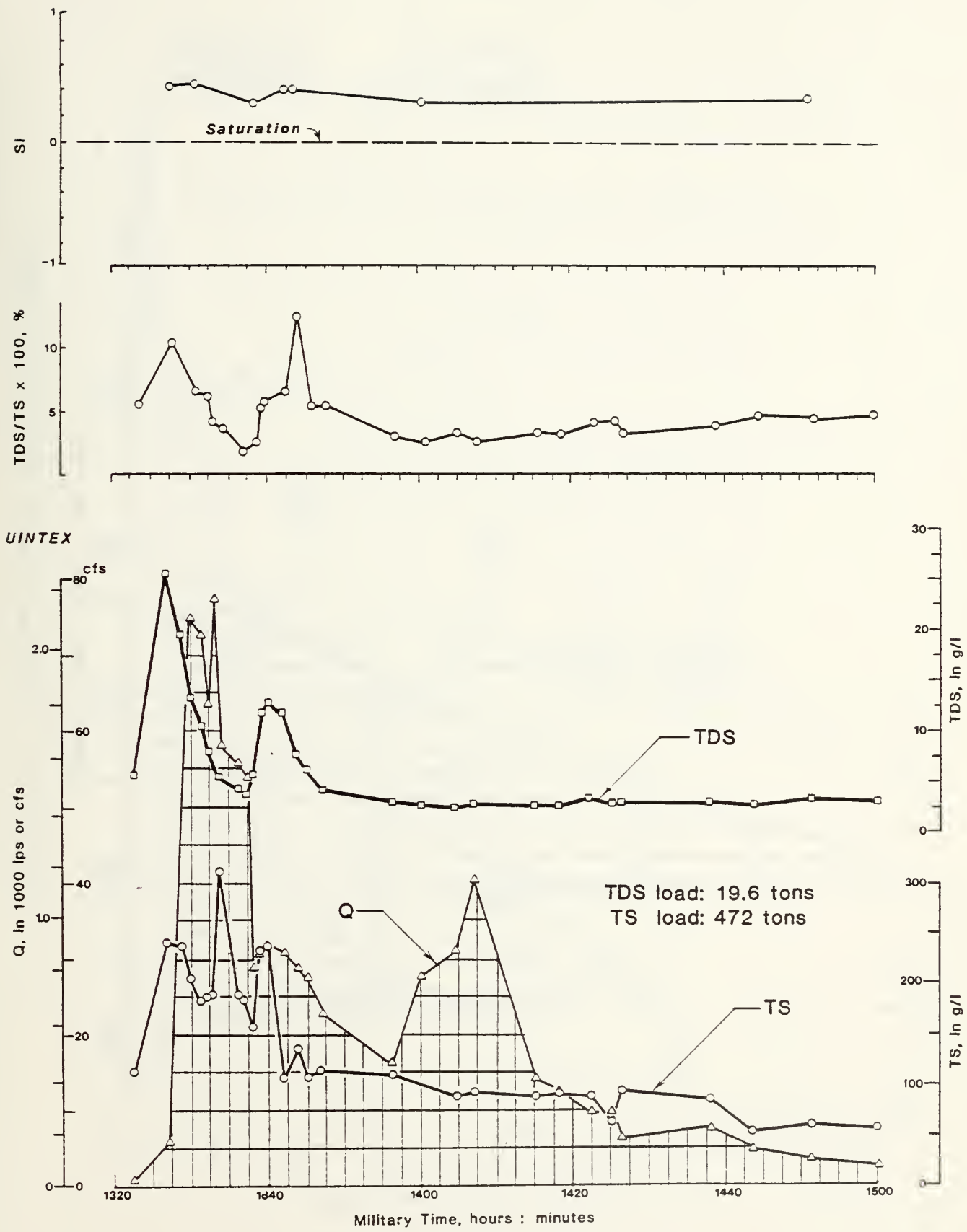


FIGURE W3.- Storm Event W10 W811003

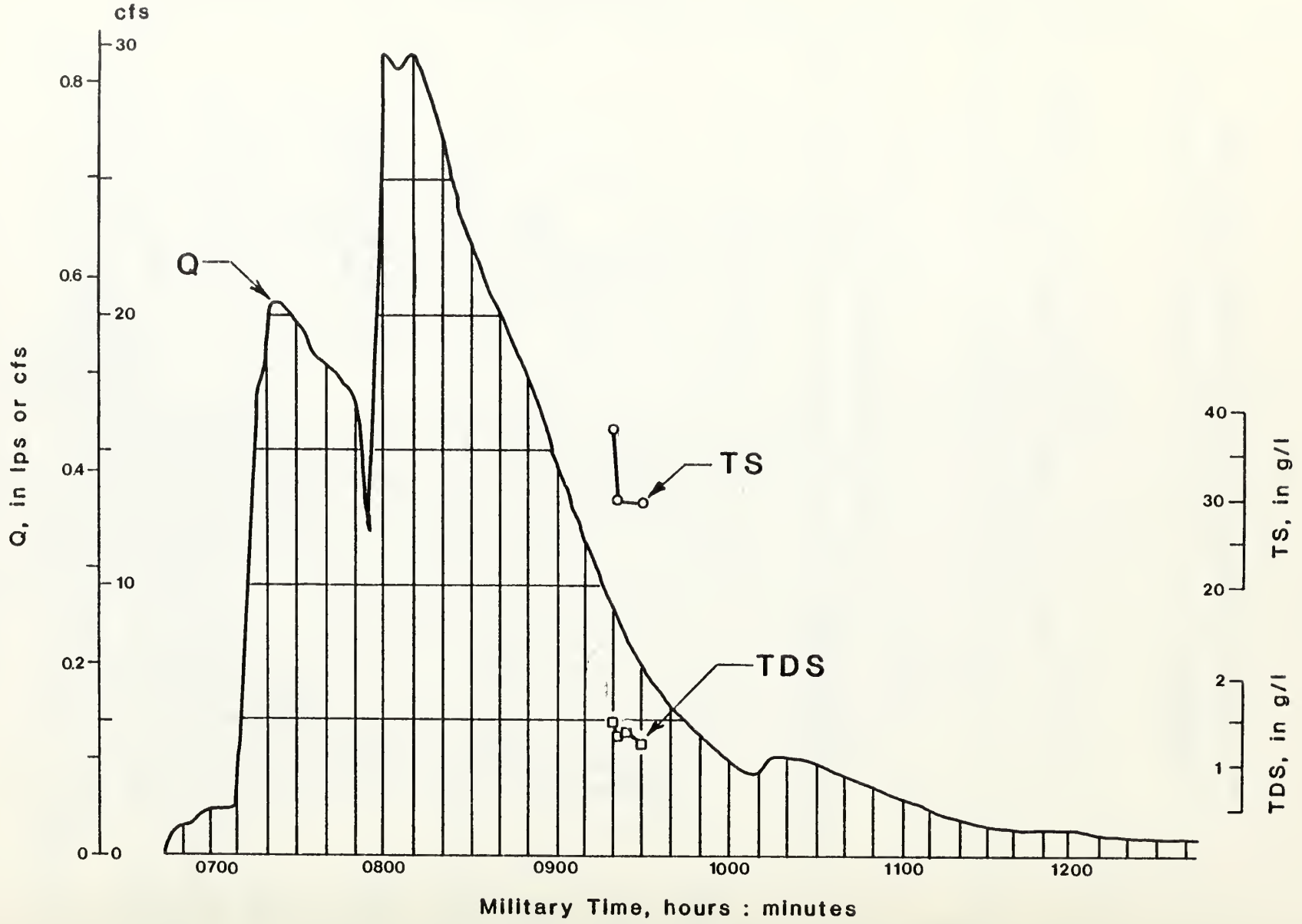
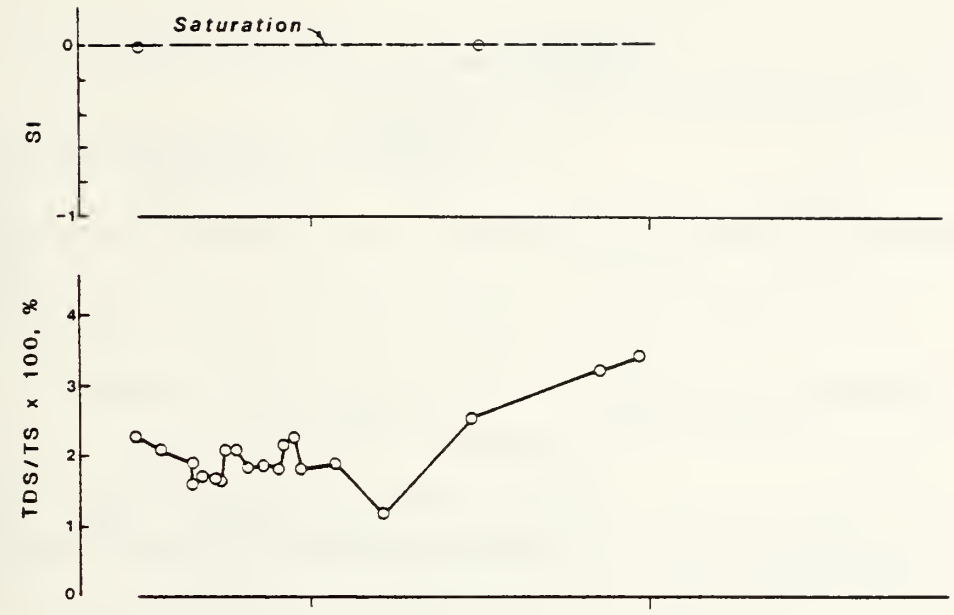


FIGURE W4.-Storm Event W811011 (AM)



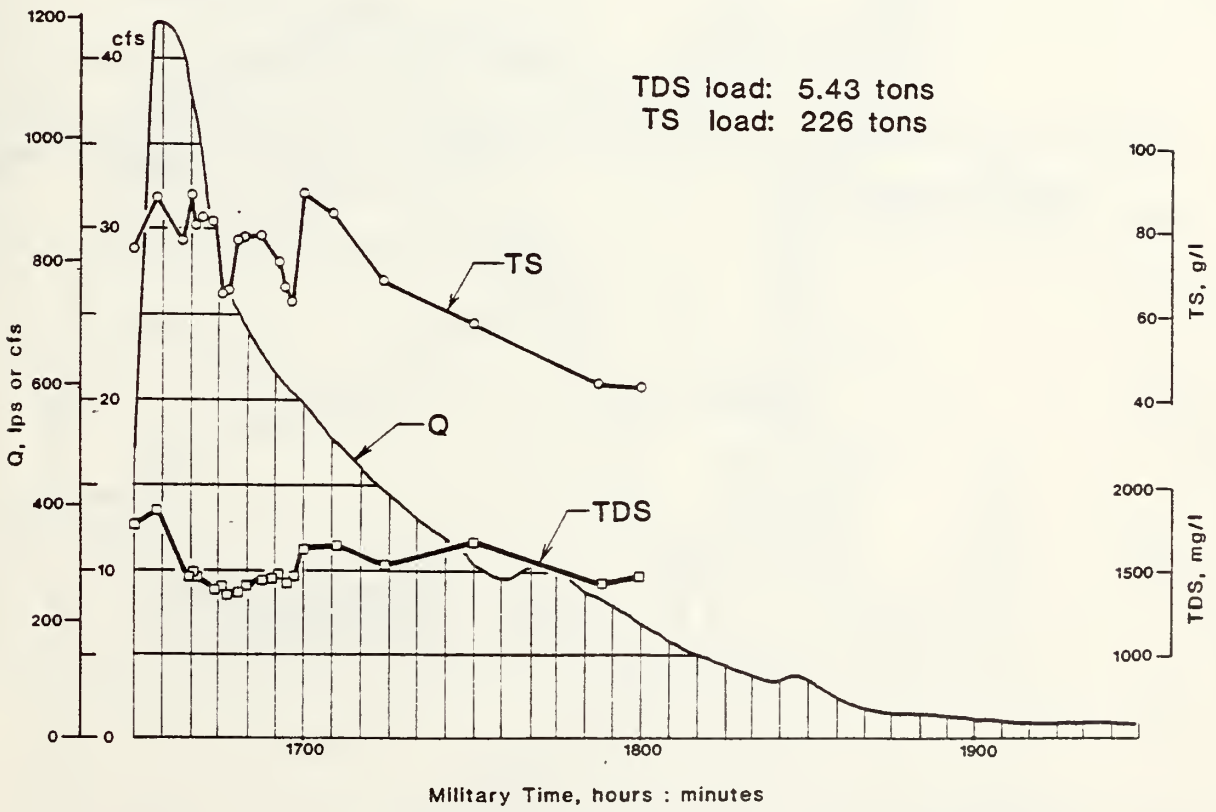


FIGURE W5.- Storm Event W811011

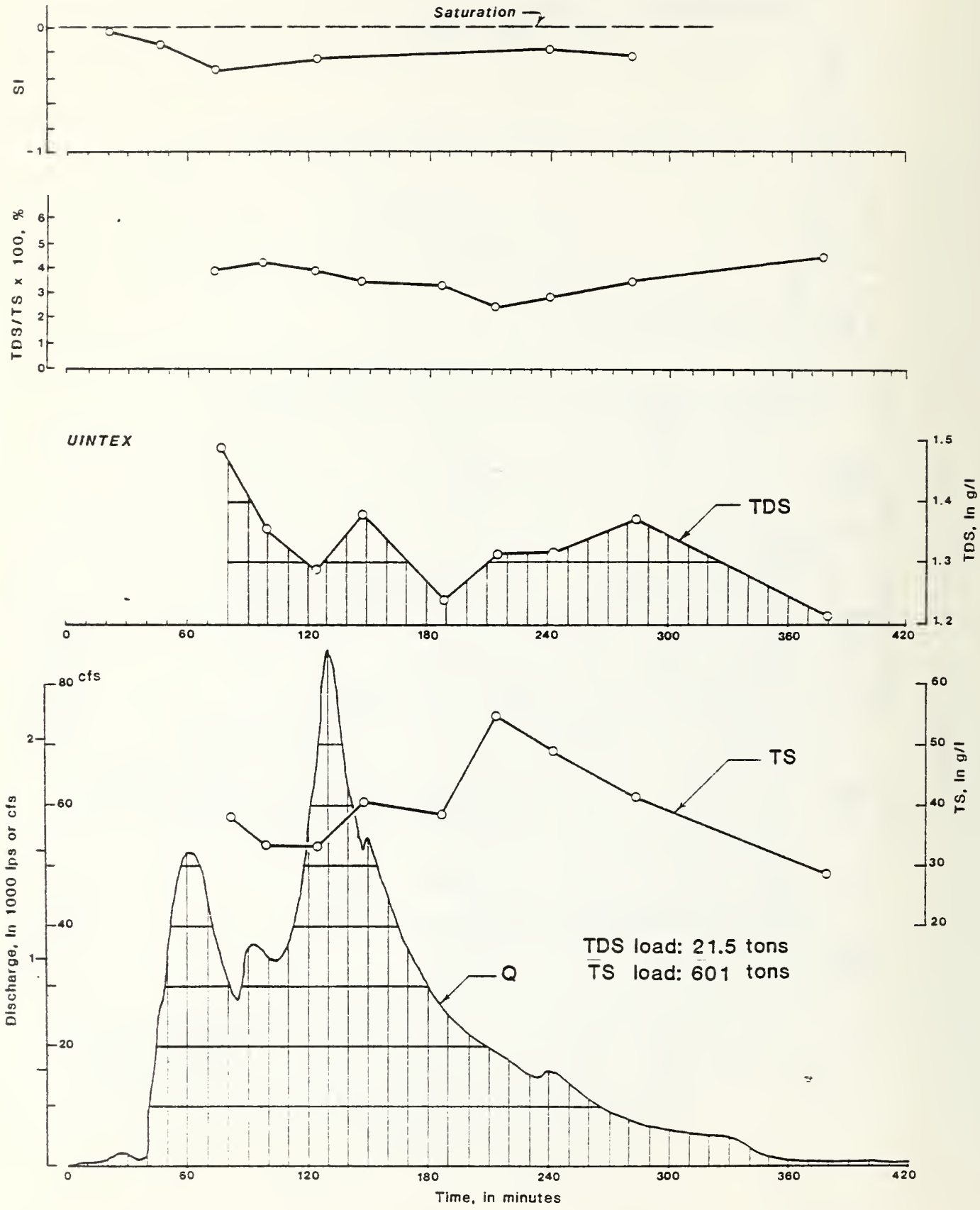
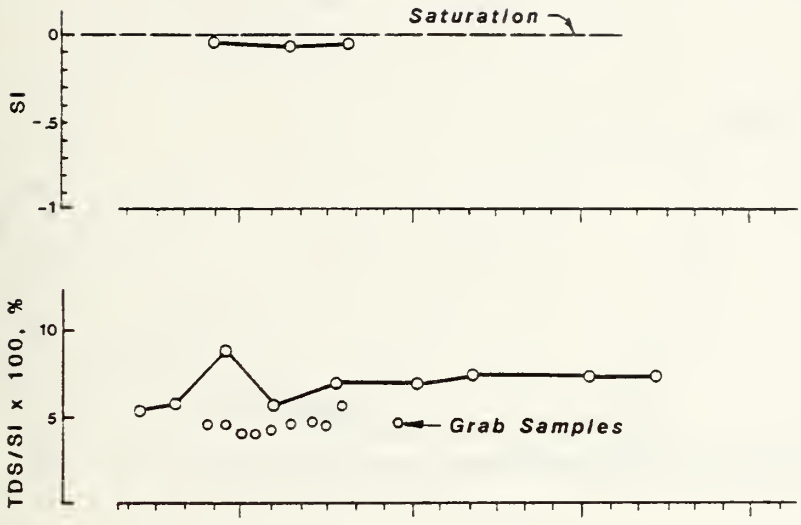


FIGURE W6.- Storm Event W811016



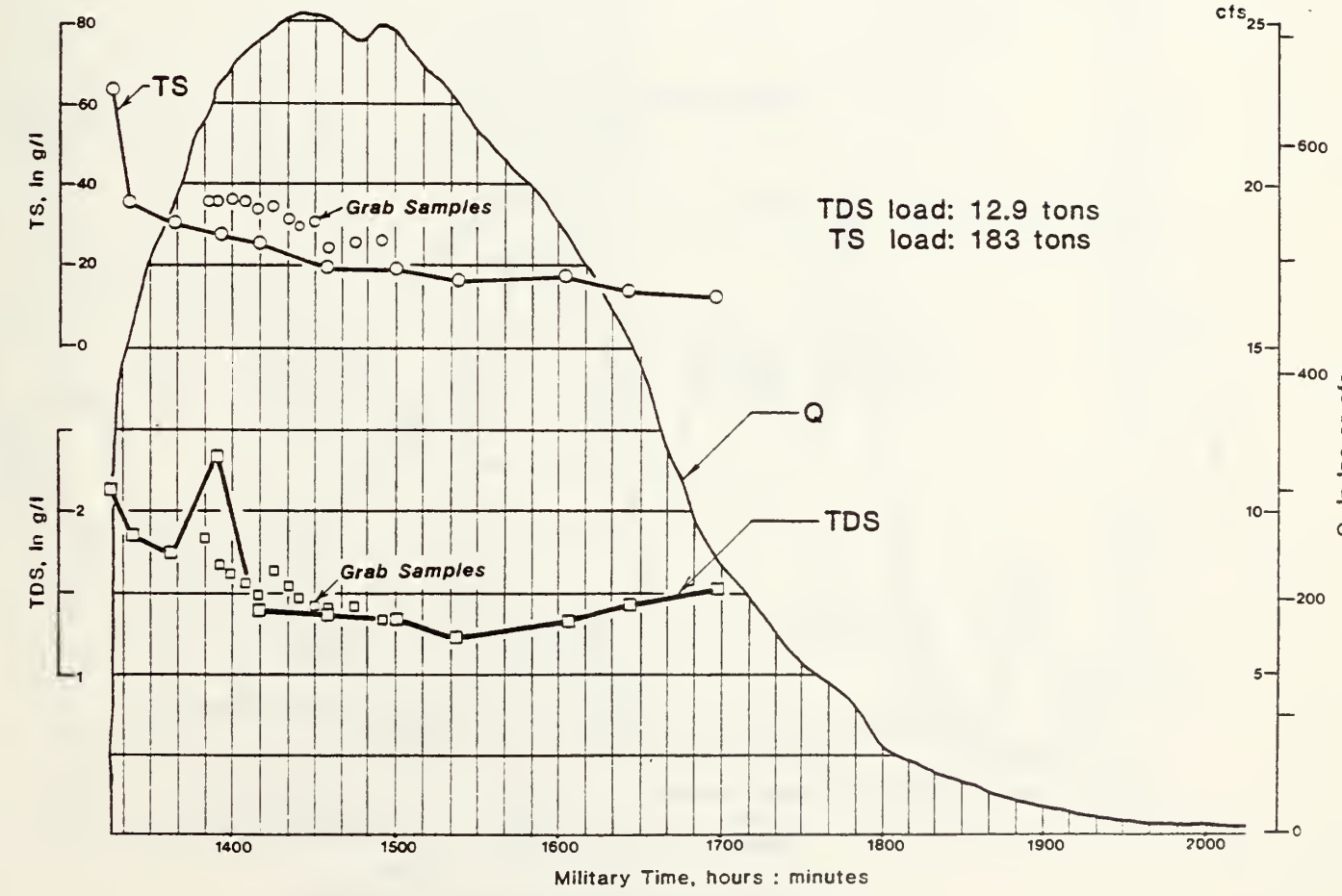


FIGURE W7.- Storm Event W811017

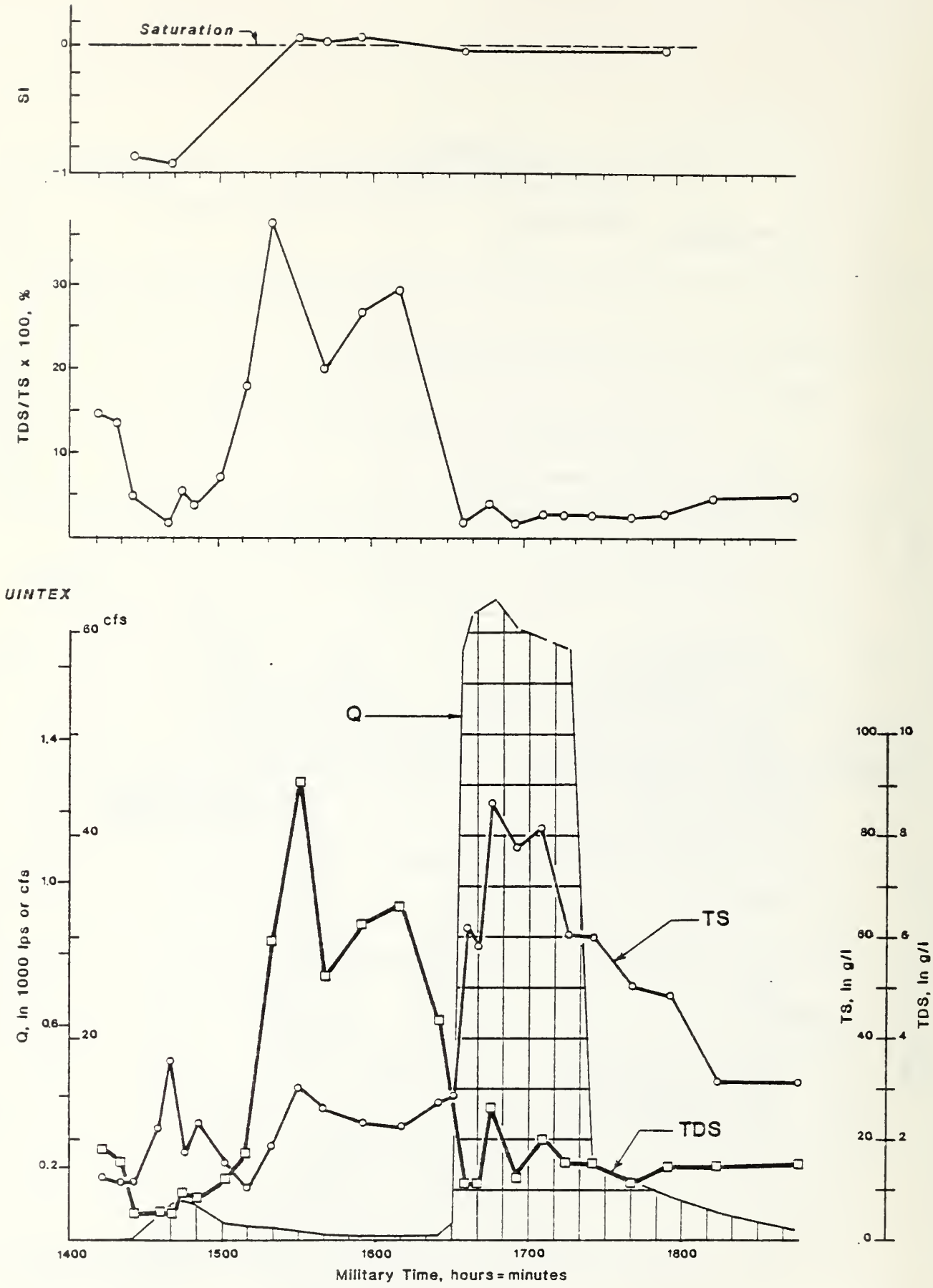


FIGURE S1.- Storm Event S811003

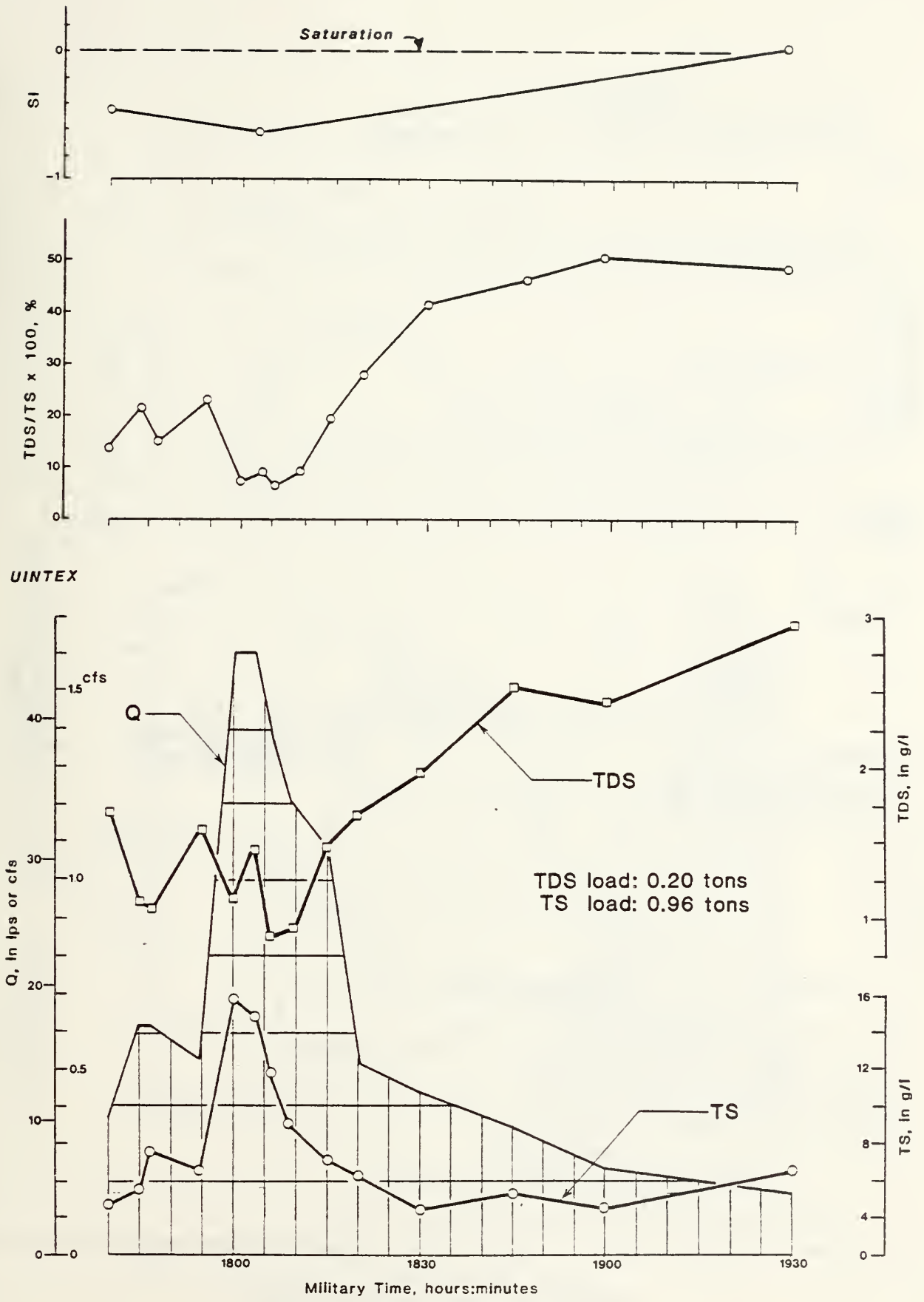


FIGURE S2.- Storm Event S811004

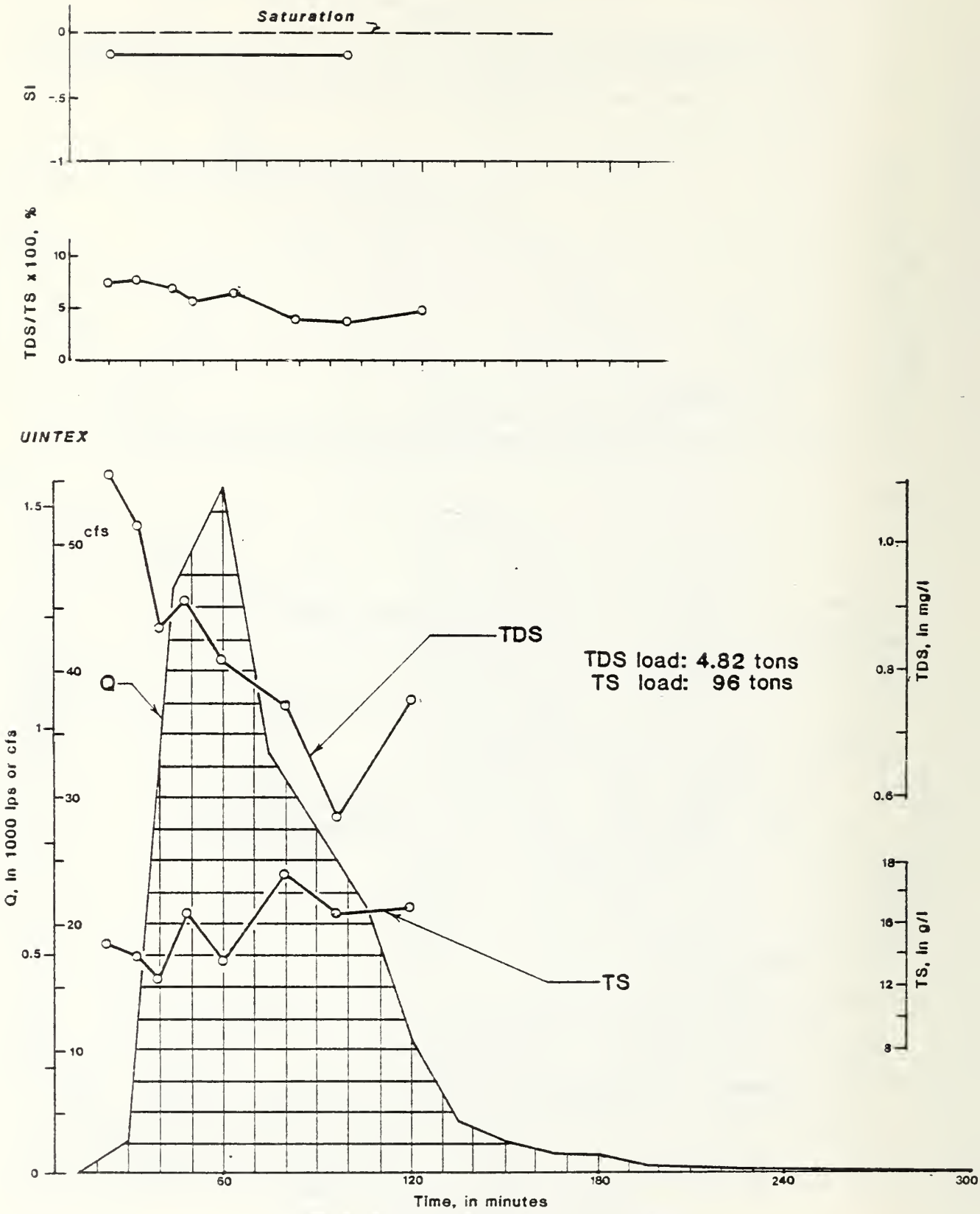


FIGURE S3.- Storm Event S811011

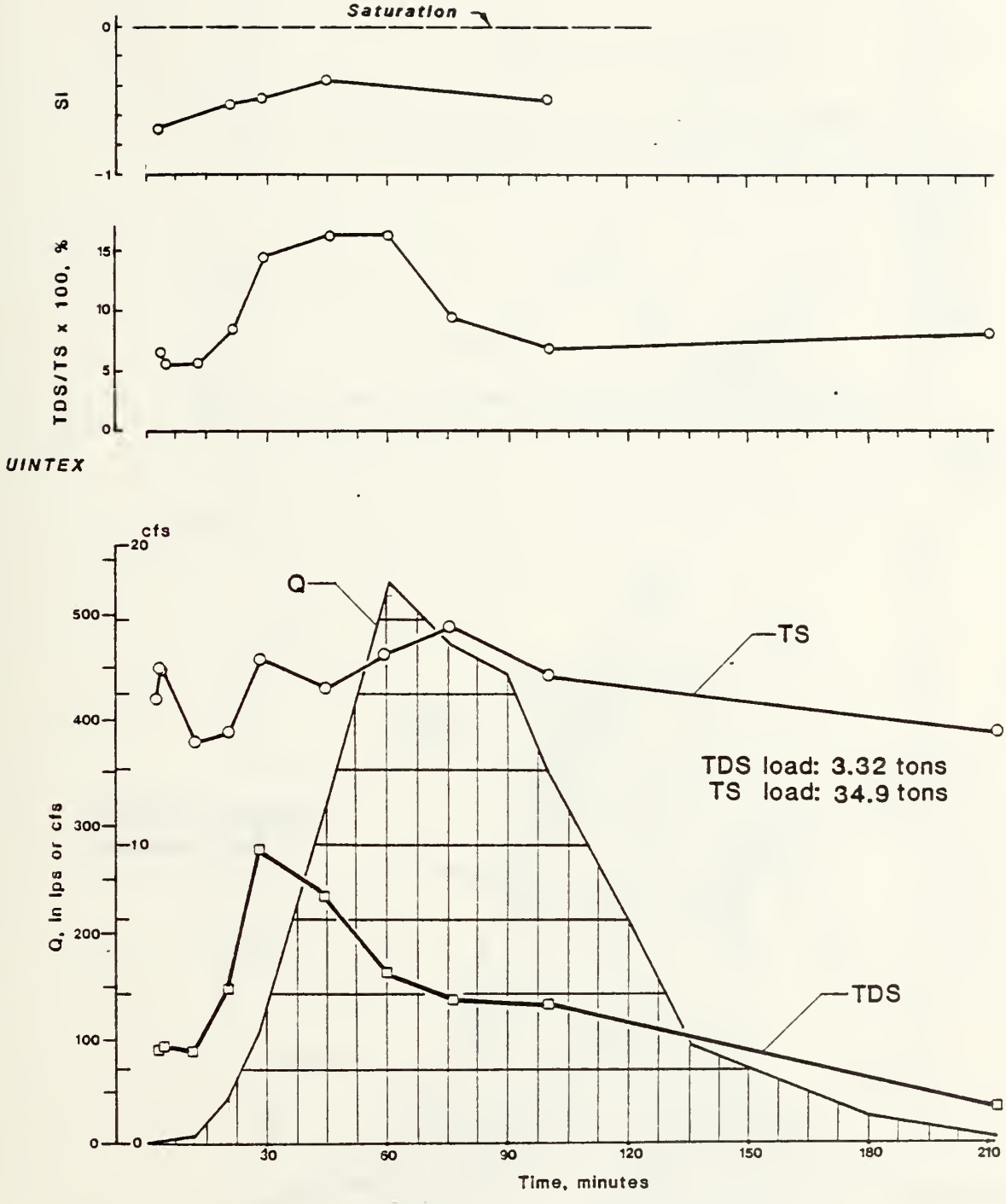
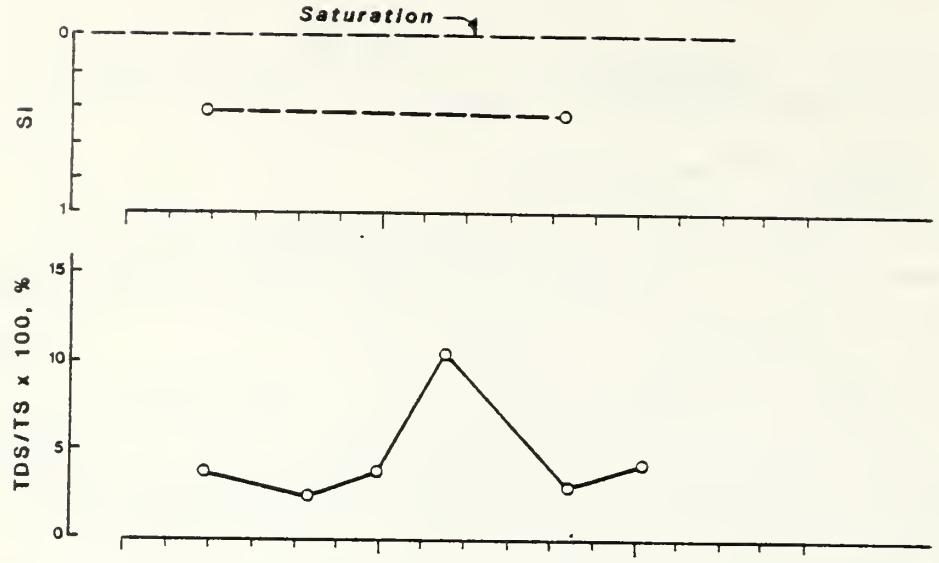


FIGURE S4.- Storm Event S811013



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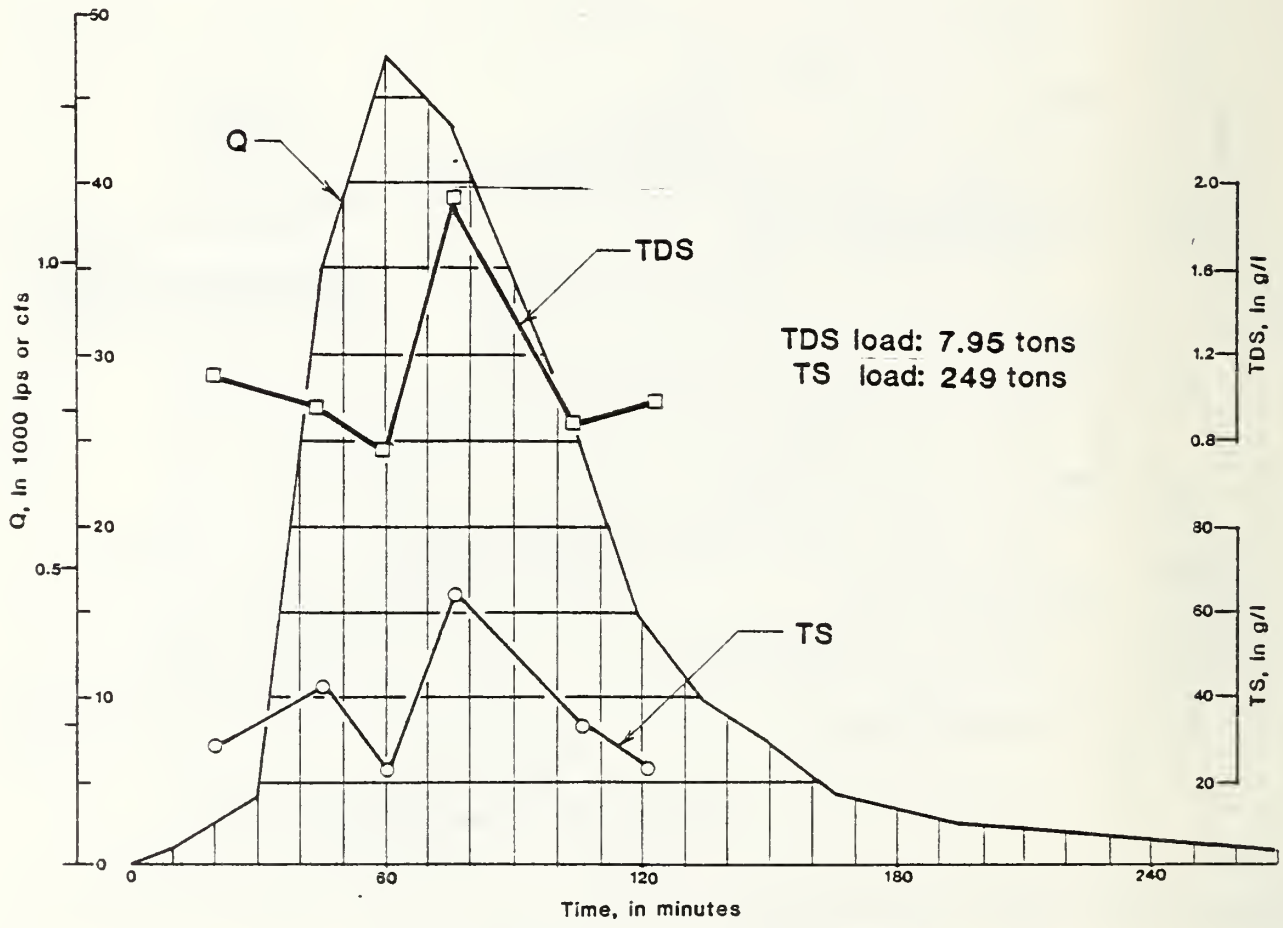
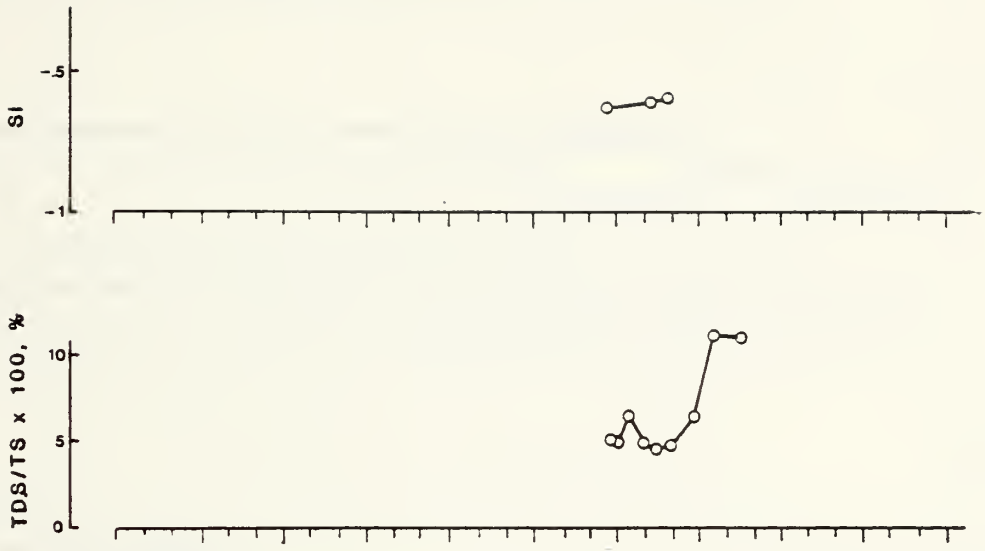


FIGURE S5.- Storm Event S811015



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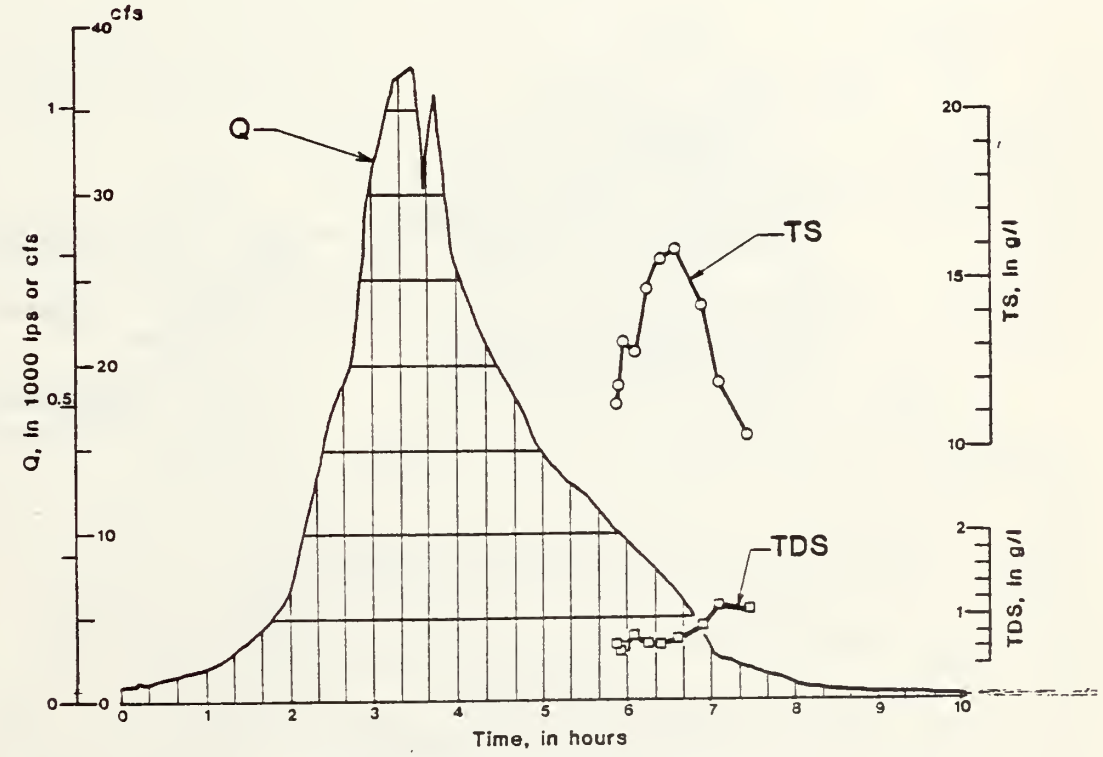


FIGURE S6.- Storm Event S811016

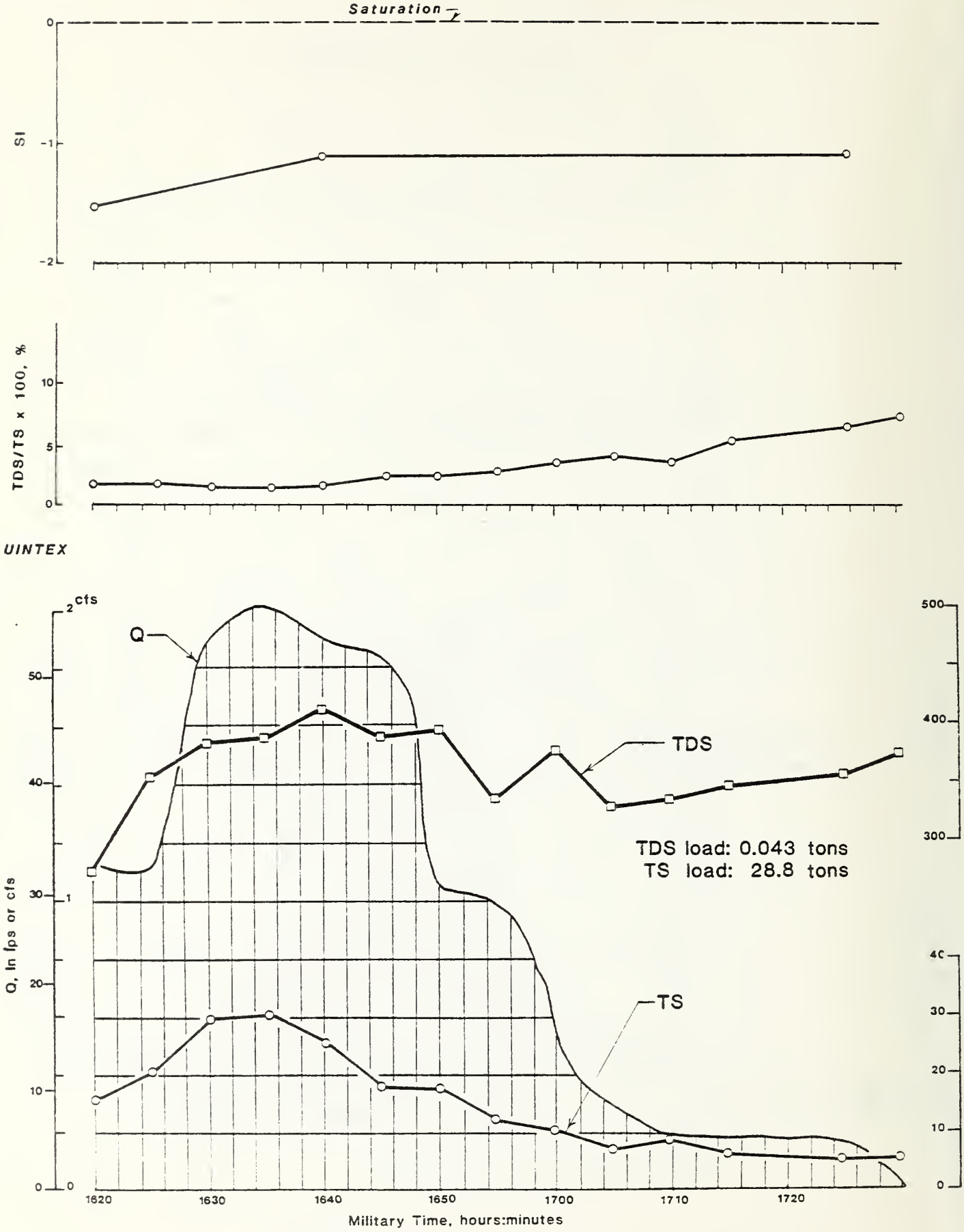


FIGURE C1.- Storm Event C811003

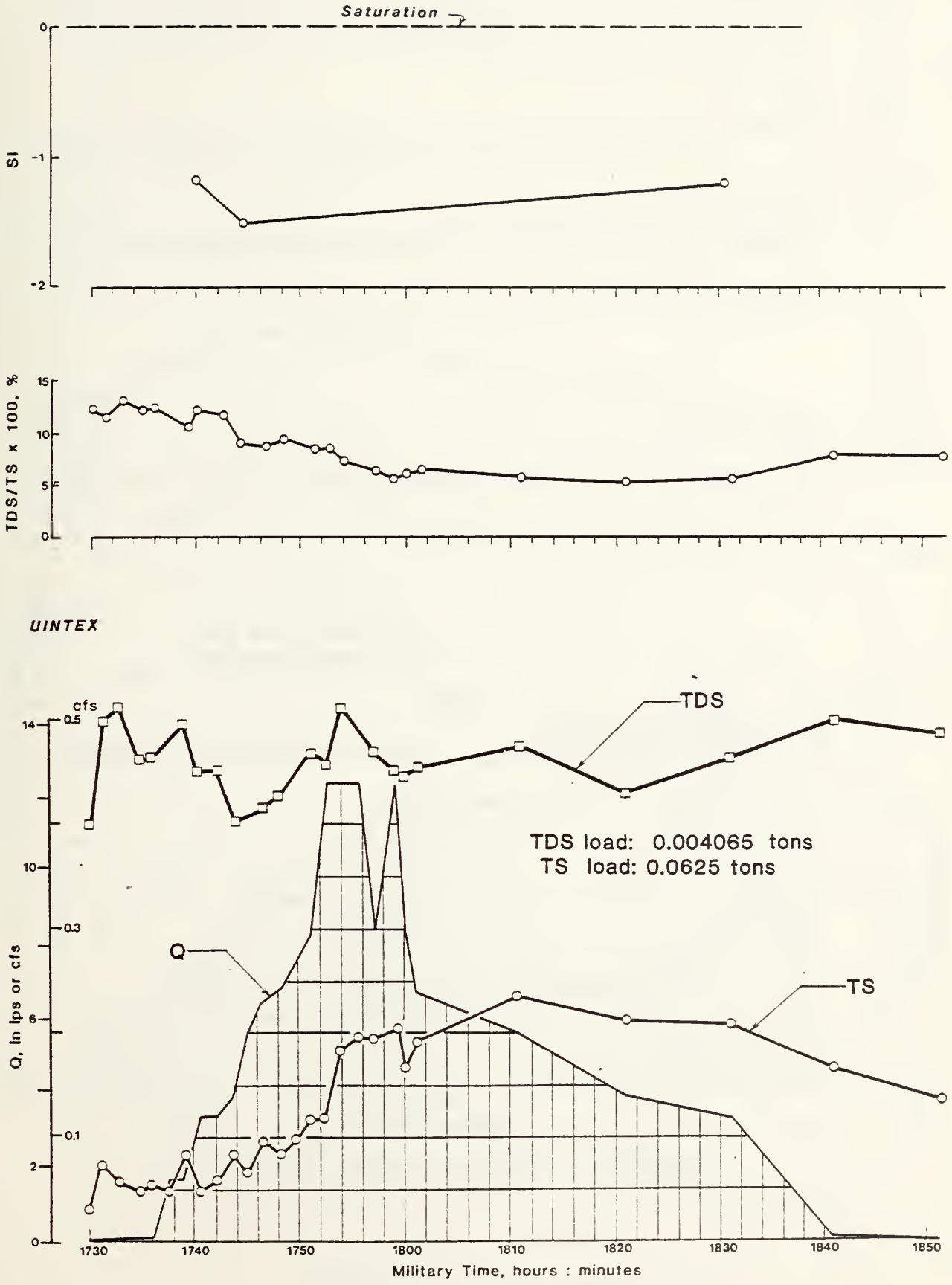


FIGURE C2.- Storm Event C811004

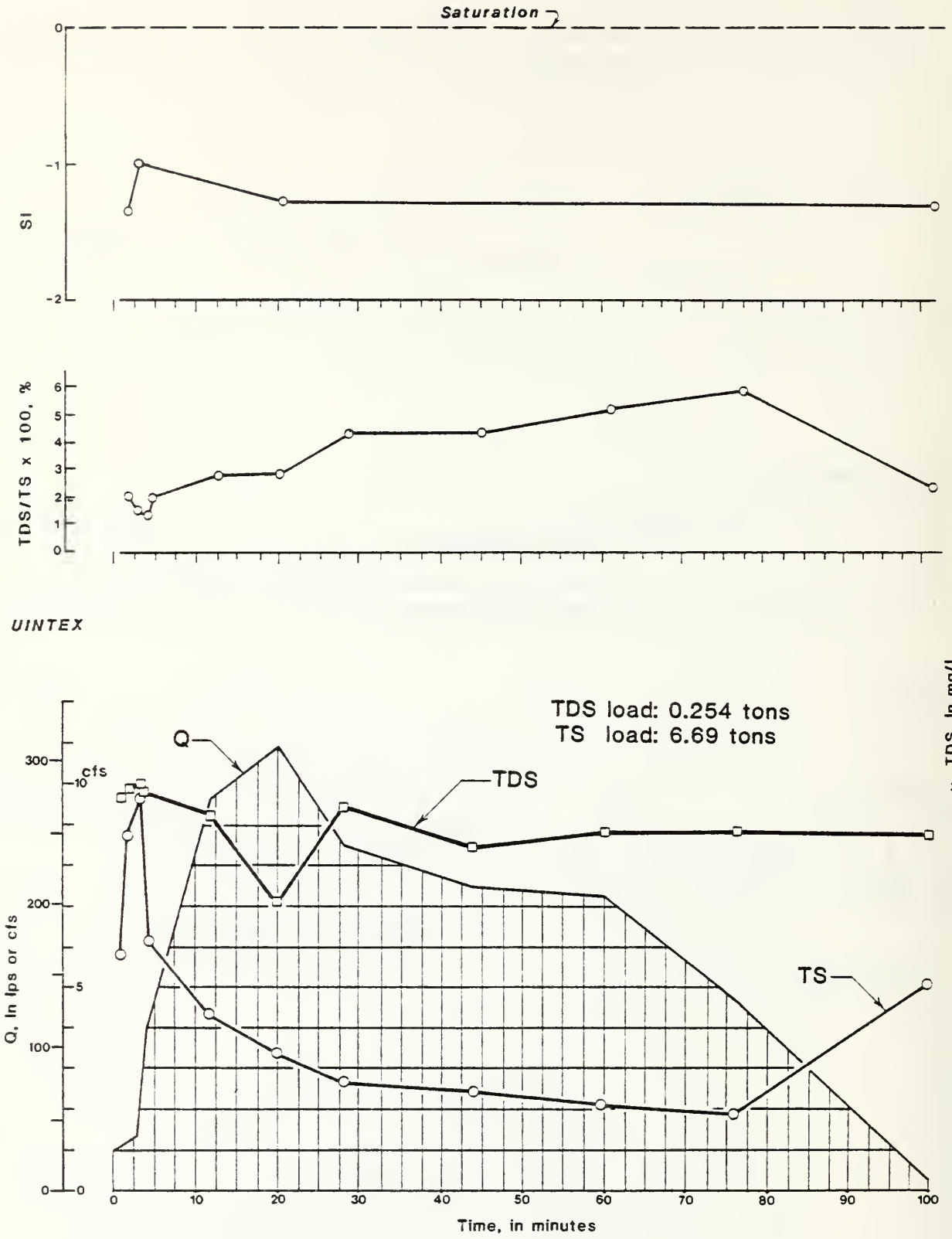
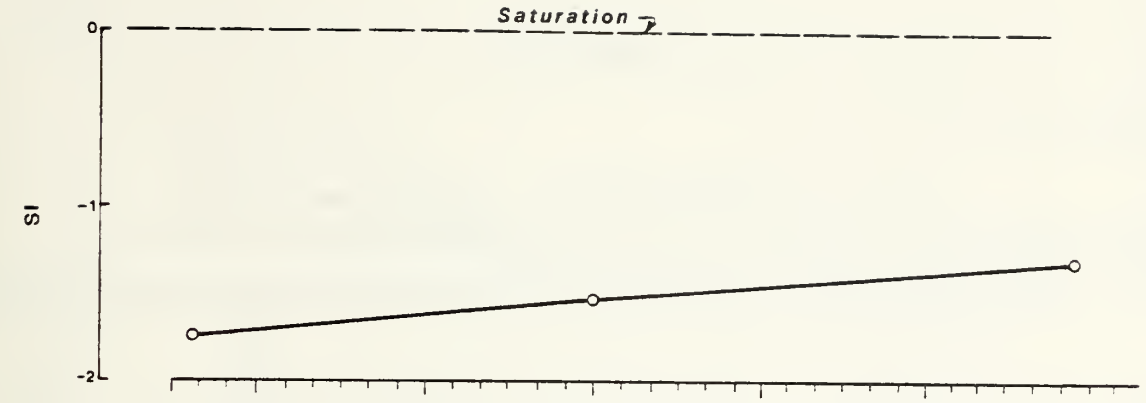
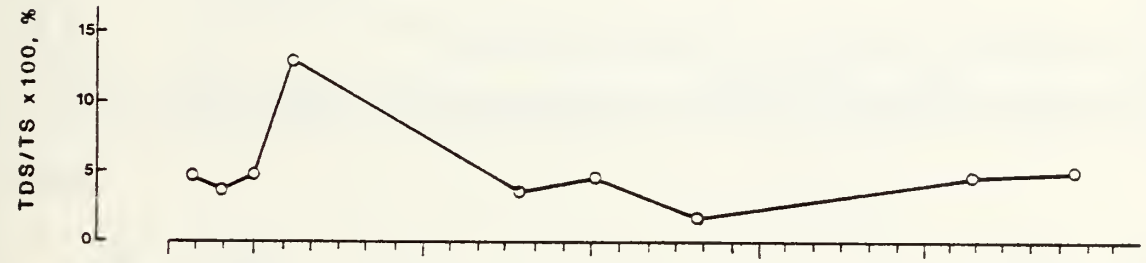


FIGURE C3.- Storm Event C81100 C811011





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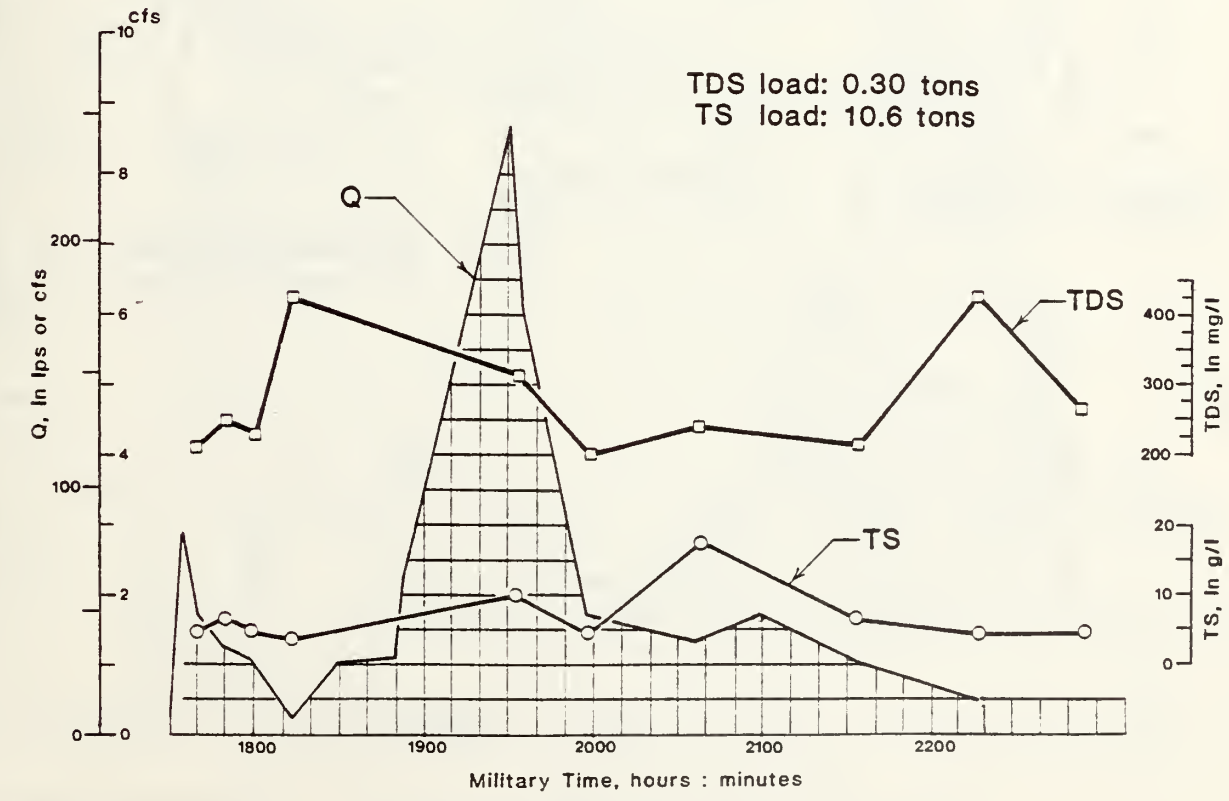

FIGURE C4.- Storm Event C811013

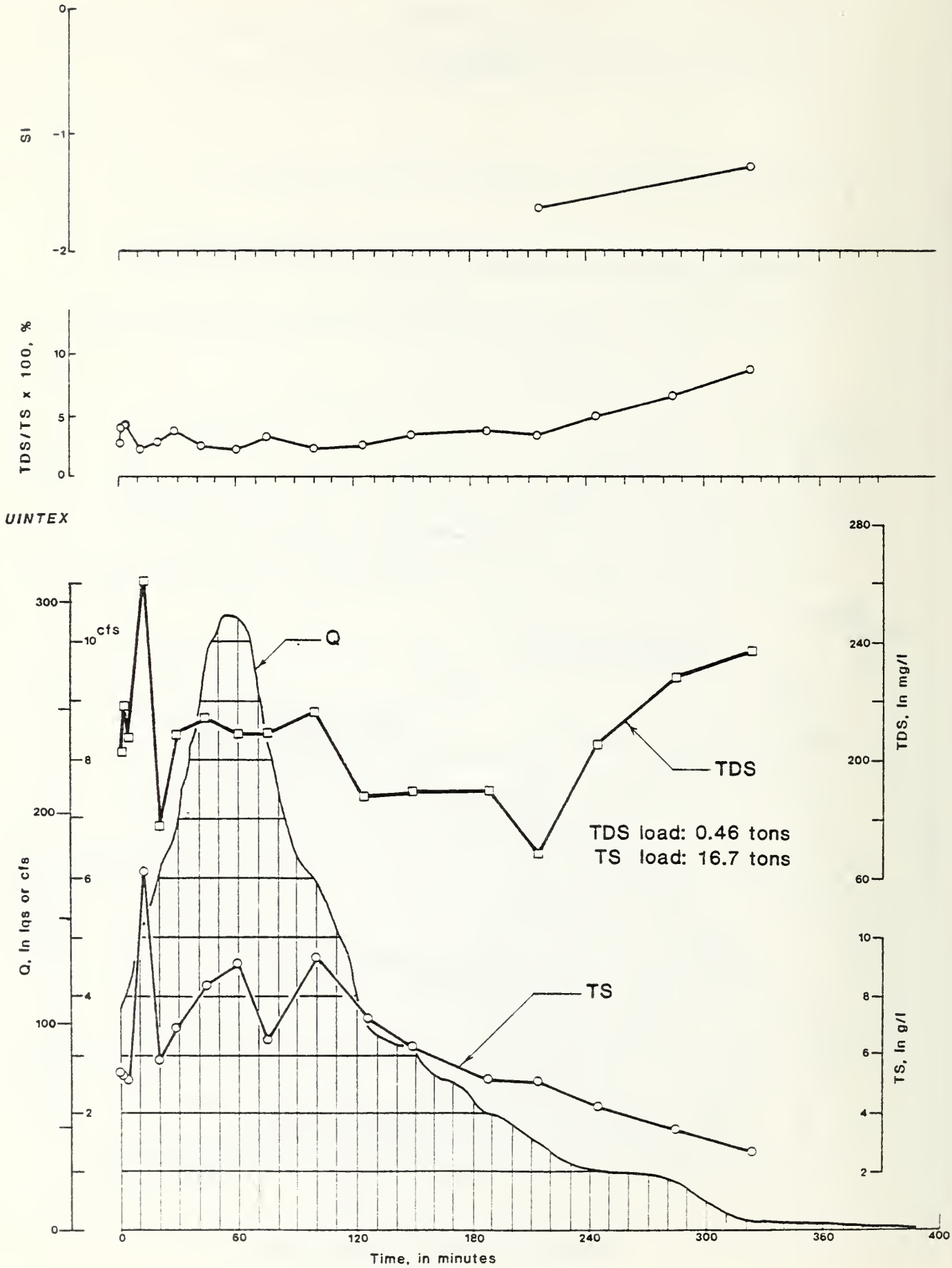

FIGURE C5.- Storm Event C811016

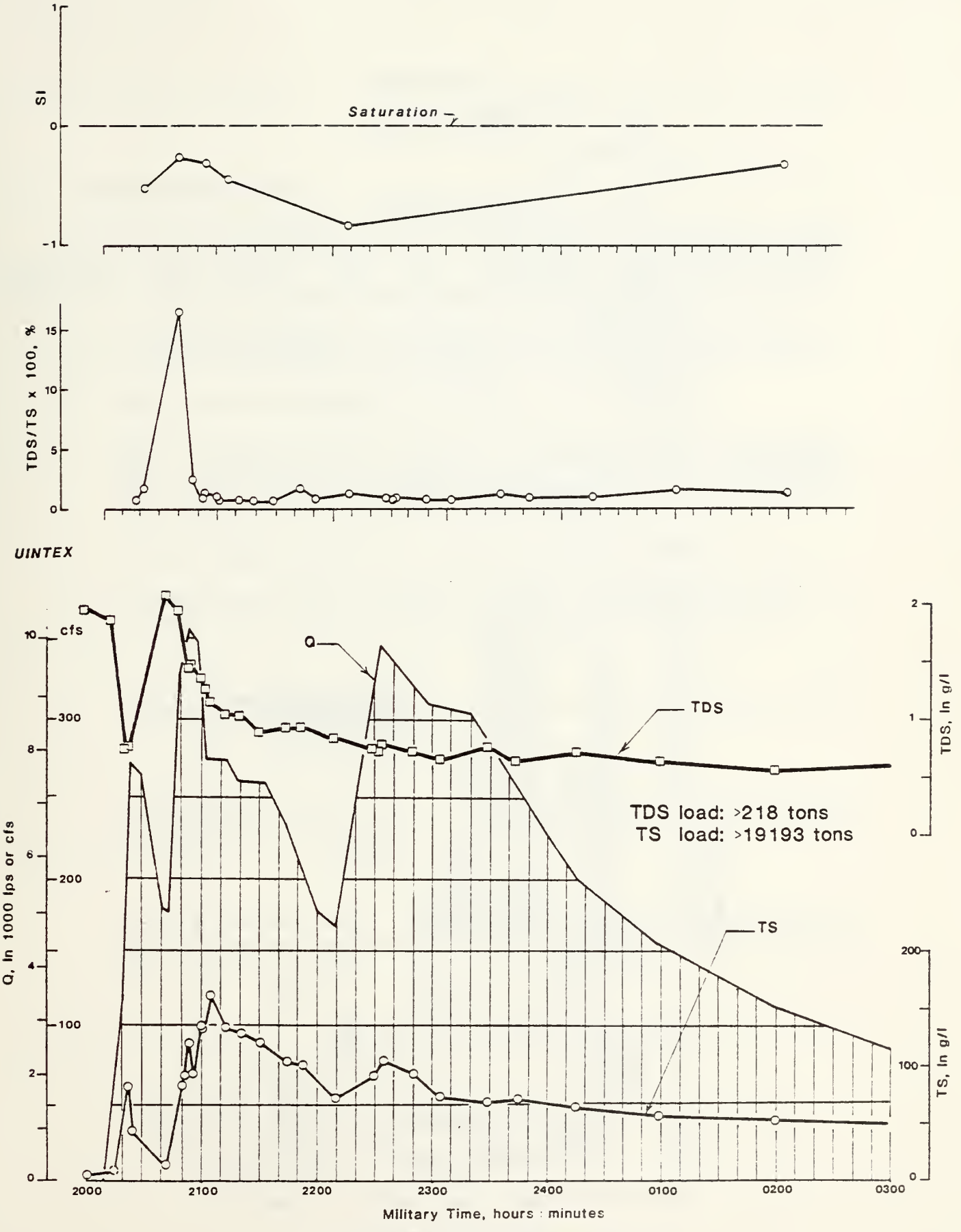

FIGURE G1.- Storm Event G811003

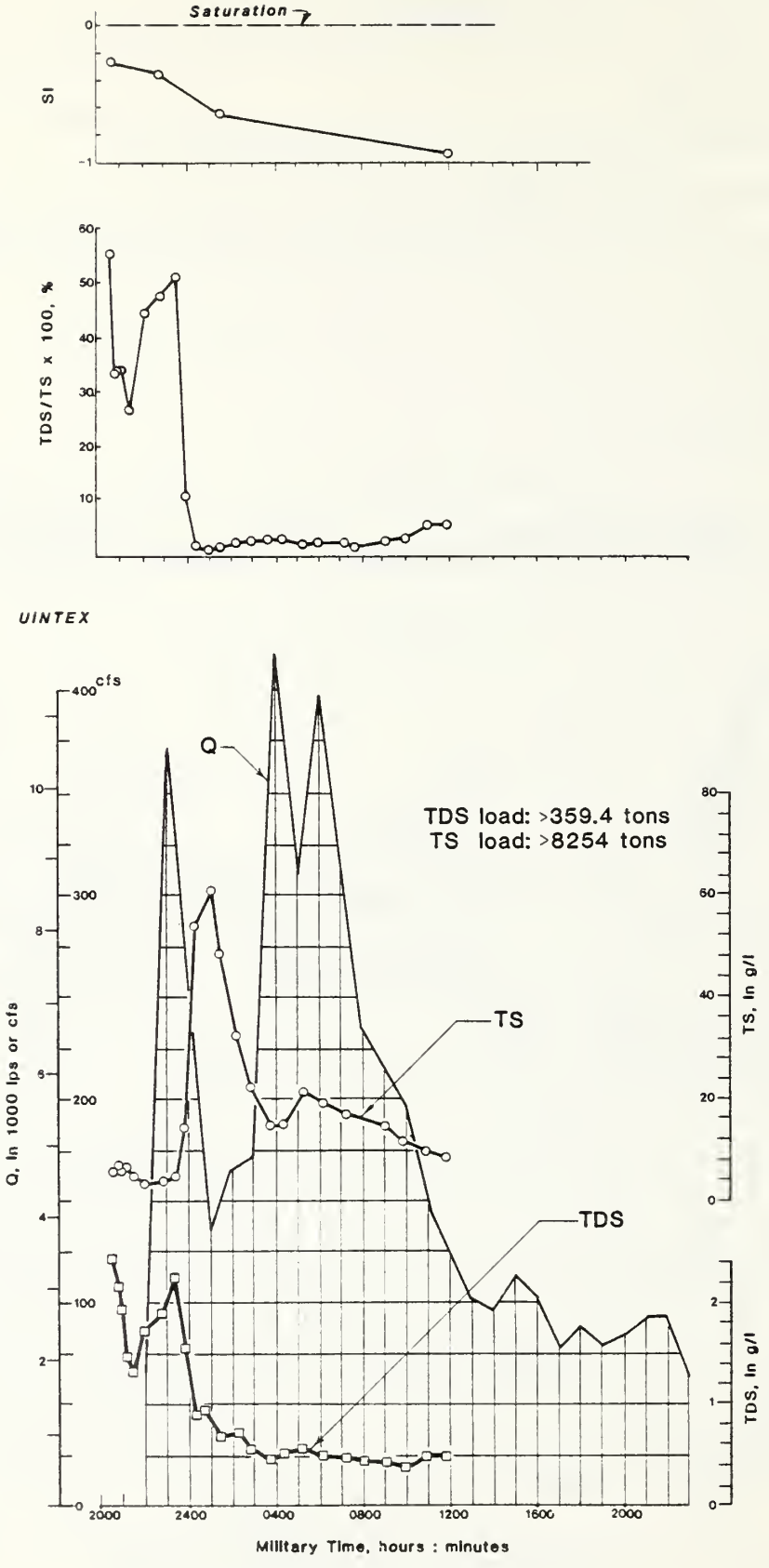

FIGURE G2.- Storm Event G811017

APPENDIX C

COMPUTATIONS

C.1 Runoff Source Area

A simplified computer program is developed to simulate runoff response to precipitation. A very simple configuration of a straight slope (Fig. C-1) was considered for this purpose. Assumptions in the program development are as follows:

a) A uniform rainfall is considered (i.e. no variation in rainfall intensity with time).

b) Flow over the surface is uniform.

c) Surface runoff occurs when the rainfall intensity exceeds the infiltration capacity of the soil (saturated hydraulic conductivity-K). Thereafter, the infiltration rate is K.

d) At the beginning of the rainfall event the soil is dry.

e) Accumulated depth of water infiltrated into the soil can be related to the time according to the relationship.

$$D = at^{b} \qquad (1)$$

where D = accumulated depth of water infiltration in the soil (inches)
t = accumulated time (hrs.)
a, b = coefficients depending on the soil

Infiltration rate f(t) is then obtained by diferentiating equation (1) with time:

$$f(t) = \frac{dD}{dt} = a\,b\,t^{b-1}$$

Using kinematic wave solutions (Woolhiser, 1977) for the above simple geometry the one-dimensional unsteady flow equation was solved:

$$\frac{\partial h}{\partial t} + \frac{\partial Q}{\partial x} = q(t) \qquad (2)$$

where h = depth of overland flow
$q(t)$ = inflow rate = excess rainfall rate = i-f(t)
Q = runoff rate per width

$$Q = \alpha h^{m}$$

for turbulant flow $\alpha = \sqrt{S_o}/n$, $m = 5/3$

So = slope
n = Manning's coeff.

The results of applying the kinematic wave theory to the given plane geometry of Fig. C1 is summarized below:

I. If the rainfall duration is longer than the equilibrium time (te) defined by equation (3):

$$te = \left\{ L_o / \left[\alpha (i - K_o/b)^{m-1} \right] \right\}^{1/m} \qquad (3)$$

then the equation for the rising hydrograph is:

$$Q = (it - at^{b})^{m} \qquad o \leq t \leq te \qquad (4)$$

For the time between equilibrium (te) and the time rain stops (to) hydrograph equation is expressed as:

$$Q = (i - Ko)\, Lo \qquad te \leq t \leq to \qquad (5)$$

The equation for the recession limb of the hydrograph is given by:

$$Q\left(\frac{i}{i - K_o}\right) - \alpha \left\{ -K_o (t - t_o) + \left(\frac{Q}{\alpha}\right)^{1/m} \right\}^{m} - K_o L_o = 0 \qquad (6)$$

II. If duration of rainfall (D) is shorter than the time of equilibrium (te), then the rising hydrograph is defined by equation (4).

Another time (De) for partial equilibrium is defined as:

$$De = D + \alpha m\, (iD - aD^{b})^{m-1} \left\{ L_o - \alpha \left(i - \frac{K_o}{b}\right)^{m-1} D^{m} \right\} \qquad (7)$$

for the time (t) after the stop of rain (to) and before De the equation for the hydrograph is:

$$Q = \alpha(iD-Kot)^{m} \qquad (8)$$

and the recesion curve is given by equation (6).

Equations (5) through (8) define the complete response hydrograph of a straight sloping plane of figure (C-1)

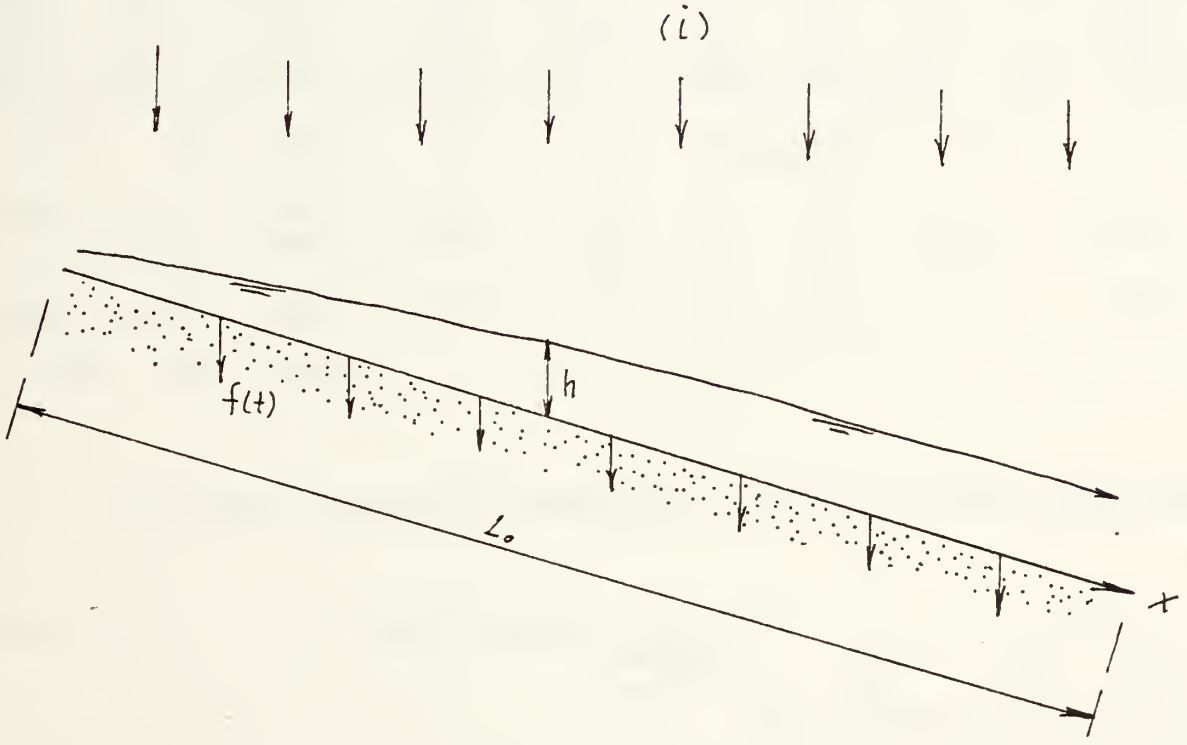

Figure C-1: Definition Sketch of Overland Flow on a Plane

C.2 USLE Estimates

SOIL LOSS POTENTIAL COMPUTATIONS FOR WATTIS WATERSHED

Section	LS	C	K	LSCK	A (annual) Tons/ac R=20	A (annual) Tons	TONS OCT. 11 EI=.3	TONS OCT. 16 EI=.35	TONS OCT. 17 EI=.44
CHD2 (4)	1.2	.24	.43	.124	2.5	160	2.4	2.8	3.5
CHD2 (3)	4.2	.24	.43	.433	8.6	495	7.5	8.7	11
CHD2 (1)	5.0	.24	.43	.516	10.32	1383	21.0	24.5	31
CHD2 (2)	4.04	.24	.43	.417	8.40	645	9.6	11.2	14.0
BL	17.79	.24	.49	2.09	41.8	20000	300	350	440
LFG3 (2)	9.71	.17	.2	.33	6.60	3040	45.8	53.4	67
LFG3 (1)	12.5	.17	.2	.425	8.50	2829	42.8	50	63
UFF2	12.9	.13	.32	.539	10.73	1717	25.5	29.7	37
						30,269	455	530	666

SOIL LOSS POTENTIAL COMPUTATION FOR SOLDIER CREEK SUBDRAINAGE

SECTION	LS	C	K	LSCK	Acres	A (annual) Tons/ac R=20	A (annual) Tons	Tons Oct. 11 EI=.26	Tons Oct. 13 EI=.24	Tons Oct. 15 EI=.86	Tons Oct. 16 EI=.43
R1A2(2)	4.92	.24	.49	.577	25.5	11.6	296	3.8	3.5	12.7	5.5
R1A2(3)	4.04	.24	.49	.475	32.0	9.5	304	4.0	3.6	13.1	6.6
R1A2(5)	2.33	.24	.49	.274	76.7	5.5	422	5.5	5.0	18.0	9.0
R1A2(1)	1.86	.24	.49	.217	48.6	4.3	209	2.7	2.5	9.0	4.5
R1A2(4)	.69	.24	.49	.081	48.1	1.6	77	1.0	1.0	3.3	1.7
IDC(2)	6.07	.13	.28	.221	64.0	4.42	283	3.6	3.4	12.1	6.2
IDC(5)	4.1	.13	.28	.149	76.8	2.98	229	2.9	2.8	9.8	4.9
							1820	23	22	78	38

SOIL LOSS POTENTIAL COMPUTATION FOR COAL CREEK SUBDRAINAGE

SECTION	L	C	K	LSCK	Acres	A (annual) R=20	A (annual) Tons	Tons Oct. 11 EI=.071	Tons Oct. 13 EI=.12	Tons Oct. 15 EI=.54	Tons Oct. 16 EI=.6
Snh	14.3	.039	.49	.273	59.6	5.46	314.5	1.1	1.9	8.1	9
PCE2(1)	10.86	.038	.49	.202	38.4	4.04	155	0.6	.9	0.5	4.5
PCE2(2)	1.78	.038	.49	.033	12.8	.663	8.5	0.0	0.0	0.2	.25
							470	1.7	2.8	8.8	14

COMPUTATION OF EI VALUES FOR WATTIS DRAINAGE

OCTOBER 11, 1981

Time	Time Interval (min)	Accumulated Depth (in)	Depth For Interval	Intensity (In/hr)	Energy Per in (ft - tons)	Energy Increment
4:00		0	0			
5:00	60	.3	.3	.3	743	223
6:30	90	.3	0	0	0	0
8:00	90	.5	.2	.133	626	125
						348
13:00	300	.5	0	0	0	0
13:10	10	.55	.05	.3	743	37
14:00	50	.55	0	0	0	0
14:40	40	.65	.1	.15	643	64
						101
						449

Max. 30 min. intensity = .3 in/hr

EI(W811011am) = 348(0.01)(0.3) = 1.044
EI(W811011) = 101(0.01)(0.3) = 0.303

OCTOBER 15, 1981

12:00 n	0					
12:00 am (1)	720	1.65	1.0	.083	554	554

EI = (554)(.01)(.083) = .46 =.5

OCTOBER 16, 1981

12:00 n	720	1.65	0	0	0	0
18:00	360	2.25	.6	.10	585	351
						351

Max. 30 min intensity = .1 in/hr

EI = (351)(.01)(.1) = .35

OCTOBER 17, 1981

9:30	30	2.25	.17	.34	761	129
10:00		2.42				

EI = (129)(.01)(.34) = .44

COMPUTATION OF EI VALUES FOR SOLDIER CREEK

OCTOBER 11, 1981

Time	Time Interval (min)	Depth (in)	Intensity in/hr	Energy/in ft-tons	Energy Incremet ft-tons
7:00am	100	.26	.156	649	169

EI = .156 (169)x .01 =.26

OCTOBER 13, 1981

9:30 10:10	40	.15	.225	701.5	105

EI =(.225)(105)(.01) =.24

OCTOBER 15, 1981

7:00pm 8:00pm	60	.3	.3	743	223
12:40pm 1:20pm	40	.1	.15	643	64
					287

EI = (.3)(287)(.01) = .86 = 0.86

OCTOBER 16, 1981

8:50am 2:50pm	360	.65	.11	599	389

EI = (389)(.11)(.01) = .43

COMPUTATIONS OF EI VALUES FOR COAL CREEK

Time	Interval (min)	Accu. Depth (in)	Depth (in)	Intensity (in/hr)	Energy/in ft-tons	Energy ft-tons
Oct. 11						
5:00am		0				
6:00	60	.65	.65	.65	854	551
9:00am		.65				
9:30am	30	.70	.05	.1	585	29
13:00		.70	0			
18:00	300	1.0	.3	.06	512	**154**
Oct. 12						
8:00am	840	1.65	.65	.046	472	307

EI(Oct. 11) = (154)(0.01)(0.046) = 0.071

Oct 13						
2:00am		1.65	0	0	0	0
6:00am		1.95	.3	.075	543	163

EI = (.075)(163)(.01) = .12 = .1

Oct. 15						
5:40		1.95	0			
6:00 pm	20	2.01	.15	.45	801	**120**
12:00	6x60	2.25	.15	.03	412	62

EI = (.45)(120)(.01) = 0.54

Oct. 16						
8:00 am		2.25	0			
14:00	6x60	3.00	.75	.125	617	463

EI = (.125)(463)(.01) = .6

Oct. 28

12:00 n		0	0			
1:00 pm	60	.7	.7	.7	865	605

EI = (.7)(605)(.01) = 4

10:00 pm						
12:00 pm	120	.15	.15	.075	544	82

EI = (.15)(82)(.01) = .1

APPENDIX D

MISCELLANEOUS DATA

D.1 Summary of Storm Events

(See attached microfiche)

D.2 Certified Results

(See attached microfiche)

D.3 Soil Characteristics of Grassy Trail Watershed

(See attached microfiche)

D.4 FORTRAN Listing of a Simple Runoff Computation

(See attached microfiche)

A **UINTEX** Report, TP822

A Study of Runoff and Water Quality
Associated with the Wildlands of
The Price River Basin, Utah

Part II:

Baseflow Runoff and Water Quality in Selected Streams of The Price River Basin, Utah

Prepared for
U.S. Department of the Interior
Bureau of Land Management
Special Studies Division
Denver Federal Center
Denver, Colorado 80225

by
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4568 Highland Drive, Suite 240
Salt Lake City, Utah 84117

July, 1982

Contract Number YA553-CT1-1064

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CHAPTER 1

INTRODUCTION

1.1 Objectives and Scope

This report documents results of a study on runoff and water quality monitored for 18 stations along selected streams in the Price River basin. The field monitoring started in late August, 1981, and finished at the end of October, 1981. The location of the monitored sites is shown in Figure 1. Among the 18 streams selected, 5 were intermittent and 13 were perennial. No baseflow records for the 5 intermittent streams are available.

There are two major components of perennial stream flow: the baseflow runoff and storm runoff. A study of salt load associated with baseflow and storm runoff in a perennial stream provides a means of differentiating salt loading of subsurface flow from that of overland runoff. Part I of this study dealt with land surface processes: erosion and in-channel pick-up. Thunderstorms and snowmelt events were shown to be major erosive forces on hillslopes underlain by marine shales. It was shown that runoff events could produce significant amounts of erosion and salinity from hillslopes.

Storm runoff and baseflow runoff components can be separated from a hydrograph in several different ways. However, for lack of a standard method to separate the storm runoff from the hydrograph, we choose to use a simple straightline delineation. In later discussions, all the baseflows involving storms are obtained from such linear delineation.

To contrast the relative importance of salt load from the baseflow with that of the storm runoff, historic runoff and electrical conductivity (EC) records at the USGS gaging station at Woodside, Utah, (0931450), are analyzed. A total of 30 episodes of major thunderstorms are identified during the period WY1969 through WY1978. To avoid the difficulty in estimating snowmelt components, only those storm occurring in July, August, September, October and November are included.

In studying baseflow characteristics, the following questions are addressed:

1) What is the average water quality (EC) of baseflows?

2) How much salinity is contributed by perennial baseflows?

3) Are baseflow conditions related to annual precipitation and irrigation diversion patterns?

1.2 Summary

The main results of this study are summarized below:

1. Eighteen stations were monitered weekly for discharge and conductivity for a period of ten weeks; among the 18 sites, five are intermittent streams.

2. Baseflow salt delivery rate at the various stations for the period of study are ranked below:

Ranking of Estimated Baseflow and Salt Delivery Rate Among the Monitored Sites

Station ID		Estimated Baseflow Salt Delivery Rate 1000 tons/year	Estimated Baseflow Runoff, cfs
18	Marsing Wash	65	30
17	Washboard Wash	20	10
3	Coal Creek at Hwy 6	7	2
13	Miller Creek at Hwy 10	3	2
2	Lower Gordon Creek	3	2
15	Icelander Creek at Hwy 6	2	<1
11	Lower Soldier Creek	2	<1

3. Baseflows during the 10-week study period at Marsing Wash and Washboard Wash combined produced a projected salt load of 85,000 tons (see also summary point #7). These baseflows reflect, in part, irrigation return flows from upstream areas. Baseflow salt contributions from other points monitored were small compared with the above-mentioned two stations.

4. Thirty episodes of major summer and fall thunderstorms were identified from the runoff records at station 09314500 (Price River at Woodside) for the months of July, August, September, October and November of the water years 1969 through 1978. Total salt load

contributed by runoff related to these thunderstorms (excluding baseflows) amounts to 218,600 tons for the 10-year period. This estimate represents 11.2% of the total salt load during the same period (1,953,000 tons).

5. Baseflows during February, April, May, and June are difficult to separate from the hydrograph. Snow-melt related runoff, erosion and water quality need to be studied in detail to isolate the salinity contributions from snow-melt events.

6. Nine weekly conductivity measurements at Marsing Wash and Washboard Wash, both in the Desert Seep Wash, indicate that the average conductivity reading ranges from 3000 to 4000 micro-mhos/cm, averaging about 3500 micro-mhos/cm, or about 2800 mg/l in total dissolved solids.

7. Since Marsing Wash and Washboard Wash are the two main tributaries of Desert Seep Wash, data from them can be used to estimate salt loads at Desert Seep Wash. Applying an average total dissolved solid concentration of 2800 mg/l, obtained from Marsing Wash and Washboard Wash, estimates of salt loads at station 09314280 (Desert Seep Wash) are given (and compared with those for Woodside station) in the following table:

Estimates of Baseflow Salt Load at Desert Seep Wash (09314280) and Salt Load at Woodside (09314500)

Water Year	Baseflow Volume (09314280) Acre-feet/year	Baseflow Salt Load tons/year	Total Salt Load at Woodside tons/year
1973	19,946	75,900	340,600
1974	11,823	45,000	155,800
1975	20,604	78,400	216,800
1976	14,975	57,000	165,800
1977	5,922	22,500	88,500
1978	7,433	28,300	119,600
1979	13,417	51,100	NA
1980	22,393	85,200	NA
1981	17,400	66,200	NA
Mean	**14,880**	**56,600**	
Standard Deviation	**5,792**	**22,000**	

8. Baseflow at Desert Seep Wash contributes about 1/4-1/3 of the total salt load at Woodside.

9. The long term trends (11 month moving averages) of baseflow at station 09314280 are not related to the long term trends of flow diversion at the Carbon Canal. This suggests that the basin-wide groundwater condition determines the trend of baseflow condition at station 09314280. The moving averages of baseflow at the station are shown to have some relationship to the winter precipitation on the basin.

10. The short term (month to month) fluctuations of baseflow at station 09314280 are shown to be related to monthly variation of flow diversion at the Carbon Canal. Cross-correlation analysis indicates that it takes about 50 days for the diverted water to percolate, seep and finally reach Desert Seep Wash. Water supply patterns of various other canals are shown to be similiar to that of the Carbon Canal. Thus, conclusions drawn about flow diversion at the canal and return flow is expected to have general application.

CHAPTER 2

BASEFLOW OF MAJOR TRIBUTARIES

This chapter will discuss baseflow characteristics, i.e. flow rate and total dissolved solid (TDS), of major tributaries. The results offer a comparison of baseflow salt load among different streams. Marsing Wash and Washboard Wash combined contributed more than 80 % of the baseflow salt load monitored among the 7 tributaries. Because of their overwhelming role, baseflow conditions of Marsing Wash and Washboard Wash are then discussed in relation to flow records at the Desert Seep Wash station, a U.S.G.S. gaging station (09314280).

2.1 Baseflow of Monitored Sites

The 18 sites selected for monitoring covered the following tributary streams of the Price River: Gordon Creek, Miller Creek, Coal Creek, Soldier Creek, Marsing Wash, Washboard Wash, and Icelander Creek (Figure 1). These streams effectively represent all the major tributaries of the basin.

The selected streams all traverse major Mancos Shale areas in the basin. A comparison of baseflows among these streams and the associated salt loads gives an indication as to which drainage area or areas have the most intense groundwater salt loading.

For the ten-week period, the monitoring of baseflows at these sites was interrupted by extensive thunderstorms during the month of October. However, there are sufficient data to estimate average baseflow discharge and EC values from the data in the month of September and last half of October. Results of weekly values in runoff and EC for each monitored station are shown in Figures 2 through 14.

It should be noted that, in reviewing the Figures, the records between October 3 through October 17 represent a series of thunderstorms. As noted previously, the frequency of sampling during the thunderstorms was not tight enough to yield meaningful information on storm events.

To compute salt load from measured discharge and EC, EC values are converted to total dissolved solids according to the regression relations reported in Part I. Average discharge and total dissolved solids are used to compute salt delivery rate. A ranking of baseflow salt delivery rate and discharge is given in the following table:

Table 1: Ranking of Estimated Baseflow and Salt Delivery Rate Among the Monitored Sites

Station ID		Estimated Baseflow, Salt Delivery Rate 1000 tons/year	Estimated Baseflow Runoff, cfs
18	Marsing Wash	65	30
17	Washboard Wash	20	10
3	Coal Creek at Hwy 6	7	2
13	Miller Creek at Hwy 10	3	2
2	Lower Gordon Creek	3	2
15	Icelander Creek at Hwy 6	2	<1
11	Lower Soldier Creek	2	<1

In view of the limited data available, only two significant digits are retained in the discharge and salt load estimate as shown in Table 1. The above ranking is meant for comparison of relative significance. Note the unit for salt delivery rate is chosen as tons per year, an estimated average rate observed during the study period.

From Table 1, it is clear that Marsing Wash and Washboard Wash combined deliver salts at an estimated rate of 85,000 tons per year during the study period. These baseflows are known to be associated with irrigation return flows in the area. All or part of the flow originates from the Carbon Canal and the Huntington-Cleveland Canal. Marsing Wash and Washboard Wash both are the major tributaries of the Desert Seep Wash; the latter has had a gaging station (09314280) since 1973. We shall study baseflow charateristics at station 09314280 to gain more insight toward the baseflow and salt load contributed by return flows from the irrigated area.

2.2 Baseflow at Desert Seep Wash Station

Although discharge records at Desert Seep Wash station have been maintained by U.S.G.S. since 1973, no historic records of EC are available. To estimate salt load from Desert Seep Wash, we shall use EC values monitored at Marsing Wash and Washboard

Wash. Readings of EC at both Marsing Wash and Washboard Wash range from 3000 to 4000 micro-mhos/cm. If an average EC is taken at 3500 micro-mhos/cm, an average total dissolved solid is estimated at 2800 mg/l.

Applying the 2800 mg/l average TDS to the baseflow records at station 09314280, an average annual salt load at the station since 1973 is estimated at 56,600 tons. A tabulation of annual salt loads are shown in Table 2. Also shown in the Table for comparison are annual salt loads at Woodside station. The total salt load at Woodside includes both baseflow and storm salt load. It is seen from the following Table that baseflow at Desert Seep Wash contributes about 1/4 to 1/3 of the total salt load at Woodside station:

Table 2

Estimates of Baseflow Salt Load at Desert Seep Wash (09314280) and Salt Load at Woodside (09314500)

Water Year	Baseflow Volume (09314280) Acre-feet/year	Baseflow Salt load tons/year	Total Salt Load at Woodside tons/year
1973	19,946	75,900	340,600
1974	11,823	45,000	155,800
1975	20,604	78,400	216,800
1976	14,975	57,000	165,800
1977	5,922	22,500	88,500
1978	7,433	28,300	119,600
1979	13,417	51,100	NA
1980	22,393	85,200	NA
1981	17,400	66,200	NA
Mean	**14,880**	**56,600**	
Standard Deviation	**5,792**	**22,000**	

CHAPTER 3

BASEFLOW OF IRRIGATED AREAS

In Table 2, it is shown that baseflow salt load passing through station 09314280 is estimated at 56,600 tons. For the period WY73-78, the estimated total annual salt load at Woodside station is about 195,000 tons. The annual quantity 56,600 tons from relatively small drainage of the Desert Seep Wash deserves further analysis. The following questions are then posed:

(1) Is there any correlation between baseflow conditions and water diversion patterns at the canal?

(2) Are baseflow conditions related to seasonal or annual precipitation patterns?

In order to resolve these questions, cross correlation and time series analysis were used to study the relationship between flow diversion at canals, flow records at Desert Seep Wash station, and precipitation records.

3.1 Long Term Conditions

To answer the first question, we look for clues on a long-term scale. Moving averages of monthly flow were used to characterize the long term trends. The monthly flow diversion quantities at Carbon Canal were used to represent irrigation water supply. They are plotted on Figure 15, (to be referred to as time series **C**). There are two reasons for chosing flow diversion at Carbon Canal:

(1) Flow records at Carbon Canal are most complete,

(2) Patterns of flow diversion at other canals are more or less similar to that of the Carbon Canal. Other canals could be chosen and they would serve the same purpose except for the completeness of records. The following Table shows the similarity of flow diversion patterns among the four major canals in the Price River Basin:

Table 3: Summary of Flow Diversion Patterns in Price River Basin, Utah

Name of Canal	Average Percent of Annual Diversion								
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Carbon	2.0	6.5	19.3	19.5	20.3	14.7	10.0	5.3	2.2
Price-Wellington	1.2	6.6	20.5	19.8	21.7	15.4	9.6	3.9	1.4
Huntington-Cleveland		4.3	13.3	20.1	22.7	17.6	12.8	9.1	
Cottonwood		2.4	18.2	26.2	21.4	14.4	9.5	7.9	

The monthly discharge at the Desert Seep Wash station is plotted on Figure 16 (time series **D**). Along with time series C and D, there are the corresponding moving averages **C** and **D**. We have tentatively chosen an 11-month period for computing the moving averages.

The moving average **D** represent the slowly changing area-wide **mean** water-table condition. The positive deviation from the moving average **D** may be interpreted as a recharging quantity and the negative deviation as a depletion of groundwater storage.

The moving average **C** suggests that the long-term pattern and quantity of flow diversion is very steady, except for the year 1977. It is obvious from the steadiness of the moving averages **C** that as long as there is sufficient water for diversion, the pattern and quantity of flow diversion is expected to be similar from year to year.

When moving averages **C** and **D** are compared, there is little relation between the mean irrigation pattern and the mean water-table condition. There is even less similarity between time series **C** (monthly diversion) and the mean water table condition of the irrigated area. In summary, we observe that the area-wide mean water-table condition is not related to the long term trend or short term fluctuations of irrigation flow diversion.

The above observation suggests that it is necessary to look for some other mechanisms that are responsible for the observed water-table conditions. Precipitation will first be examined as

a contributing natural parameter. Precipitation records at Hiawatha and Price Warehouse are combined to form a basin average precipitation condition. There are some missing records in both of the two stations. Fortunately, no records are missing simultaneously at the two stations. Arithematic averages are then taken where applicable; where there is a record missing at one station, the record of the other is used as the average. Thus, an estimated complete set of records from 1973 to 1980 is composed.

We assume first that the precipitation accumulated as snowfall for the months December, January, February, March, and April is responsible for most of the baseflow for the water year. We also assume that thunderstorms which occurred during the months July through November readily yield surface runoff, exerting smaller influence on the baseflow.

To test the validity of the stated assumptions, a simple linear correlation between the winter precipitation and annual baseflow (accumulated from February through the following January) at Desert Seep Wash station is performed. The correlation coefficient is 0.58. Table 4 and Figure 17 show the tablated and graphical presentation of the data set.

Table 4: Estimated Basin Winter Precipitition and Annual Baseflow at Desert Seep Wash

Year	Precipitation (snow), inches, December through April	Annual Baseflow at 09314280, February through January Acre-feet
1973	3.03	19401
1974	1.90	11676
1975	3.27	22309
1976	3.03	11672
1977	.95	2632
1978	5.15	9760
1979	6.90	14098
1980	9.11	24556

The data suggest a relationship between the winter precipitation and baseflow volume at the station. More insights can be gained if the analysis is refined to include the following:

(1) Relate baseflow volume to both winter and thunderstorm precipitaitons.
(2) Use cross correlation to determine sequential relationship between precipitation and baseflow.

If the mean baseflow (moving average **C**) is related to precipitation, particularly precipitation in the form of snowfall, questions for future study include:

(1) Why does so much baseflow show up in the Desert Seep Wash? Is there an extensive groundwater aquifer in the irrigated area? Or does irrigation efficiency vary from year to year according to precipitation conditions?

(2) From management view point, how much of the baseflow is really contributed by irrigation activity and thus subject to control and management?

3.2 Short Term Fluctuations

Although there is little relationship between the long term behavior of baseflow at Desert Seep Wash and irrigation water supply represented respectively by moving averages **D** and **C**, the fluctuations around the moving averages show definite connections.

When the moving averages **C** and **D** are removed from their corresponding time series, we are left with the filtered time series **C** and **D** as shown in Figures 18 and 19.

Some insight may be gained if we place the two filtered time series **C** and **D** alongside each other and compare their values month-to-month first without any time lag, and then compare them with one-month time lag, and then two-month time lag, and so on. For example, at one-month time lag we would be comparing values of February at Desert Seep Wash with those of January at Carbon Canal. The formal process of such comparison is called a cross-correlation. The cross-correlation S(k) with time lag k (in month) is computed according to the following formula:

$$S(k) = \mathbf{C}(t)*\mathbf{D}(t+k)/SQR(\mathbf{C}SD*\mathbf{D}SD)$$

where **C** and **D** are the filtered time series **C** and **D**
n represents some appropriate sample size,
CSD and **D**SD are standard deviations of filtered **C** and **D** respectively.

Results of cross-correlation analysis are shown in Figure 20.

It is clear from the Figure that the highest cross-correlation between filtered **C** and **D** occurred between time lag 1 month to 2 month. A cursory evaluation of the cross-correlation curve suggests that the maximum cross-correlation takes place at a 50-day lag. This may suggest that it would take 50 days for a drop of diverted water to percolate, seep and finally find its way to the Desert Seep Wash, if it ever reaches the Desert Seep Wash at all.

CHAPTER 4

DISCUSSION AND RECOMMENDATIONS

Results of this study are summarized in section 1.2. There is no question that baseflow monitored at Desert Seep Wash contributes a considerable portion of total total salt load of the basin. Baseflow at Desert Seep Wash station alone contributes about 30 % (56600/195000) of the total salt load passing through Woodside station. However, how much of this 56,600 tons of salt comes from irrigated areas and how much from the un-irrigated areas remain unresolved. The answer to this question will also answer the question as to how much of the baseflow-related salt load is controllable.

At issue here is whether there exists an extensive aquifer which transmits natural water from both the irrigated and the un-irrigated areas to recieving streams in the form of baseflow. There is not sufficient data to make any determination. This can only be determined from a field monitoring program. A well conceived groundwater monitoring plan and some computer analysis can quantify the basin wide groundwater flow condition and determine how much of the baseflow salt load (e.g. 56,600 tons at Desert Seep Wash) is from un-irrigated area and how much from the irrigated area.

The cross-correlation between the irrigation flow diversion and baseflow at receiving streams points out the residence time of deeply percolated water in irrigated lands. It also suggest a method for studying the net irrigation efficiency. That is, if we know the time lag between the water supply time series and the return flow time series, it is feasable to line up the two time series and study the net irrigation efficiency.

APPENDIX A

FIGURES

List of Figures

Figure 1 - Estimated Baseflow Salt Load at Selected Stations in the Price River Basin, Utah.

Figure 2 - Weekly Discharge, Conductivity and Salt Delievery Rate. Site #1, Upper Gordon Cr.

Figure 3 - Weekly Discharge, Conductivity and Salt Delievery Rate. Site #2, Lower Gordon Cr.

Figure 4 - Weekly Discharge, Conductivity and Salt Delievery Rate. Site #3, Coal Cr.

Figure 5 - Weekly Discharge, Conductivity and Salt Delievery Rate. Site #9, Upper Coal Cr.

Figure 6 - Weekly Discharge, Conductivity and Salt Delievery Rate. Site #10, Soldier Cr.

Figure 7 - Weekly Discharge, Conductivity and Salt Delievery Rate. Site #11, Soldier Cr.

Figure 8 - Weekly Discharge, Conductivity and Salt Delievery Rate. Site #12, Soldier Cr.

Figure 9 - Weekly Discharge, Conductivity and Salt Delievery Rate. Site #13, Miller Cr.

Figure 10 - Weekly Discharge, Conductivity and Salt Delievery Rate. Site #14, Icelander Cr. trib.

Figure 11 - Weekly Discharge, Conductivity and Salt Delievery Rate. Site #15, Icelander Cr.

Figure 12 - Weekly Discharge, Conductivity and Salt Delievery Rate. Site #16, Horse Canyon.

Figure 13 - Weekly Discharge, Conductivity and Salt Delievery Rate. Site #17, Washboard Wash.

Figure 14 - Weekly Discharge, Conductivity and Salt Delievery Rate. Site #18, Marsing Wash.

Figure 15 - Monthly Flow Diversion and Moving Averages, Carbon Canal.

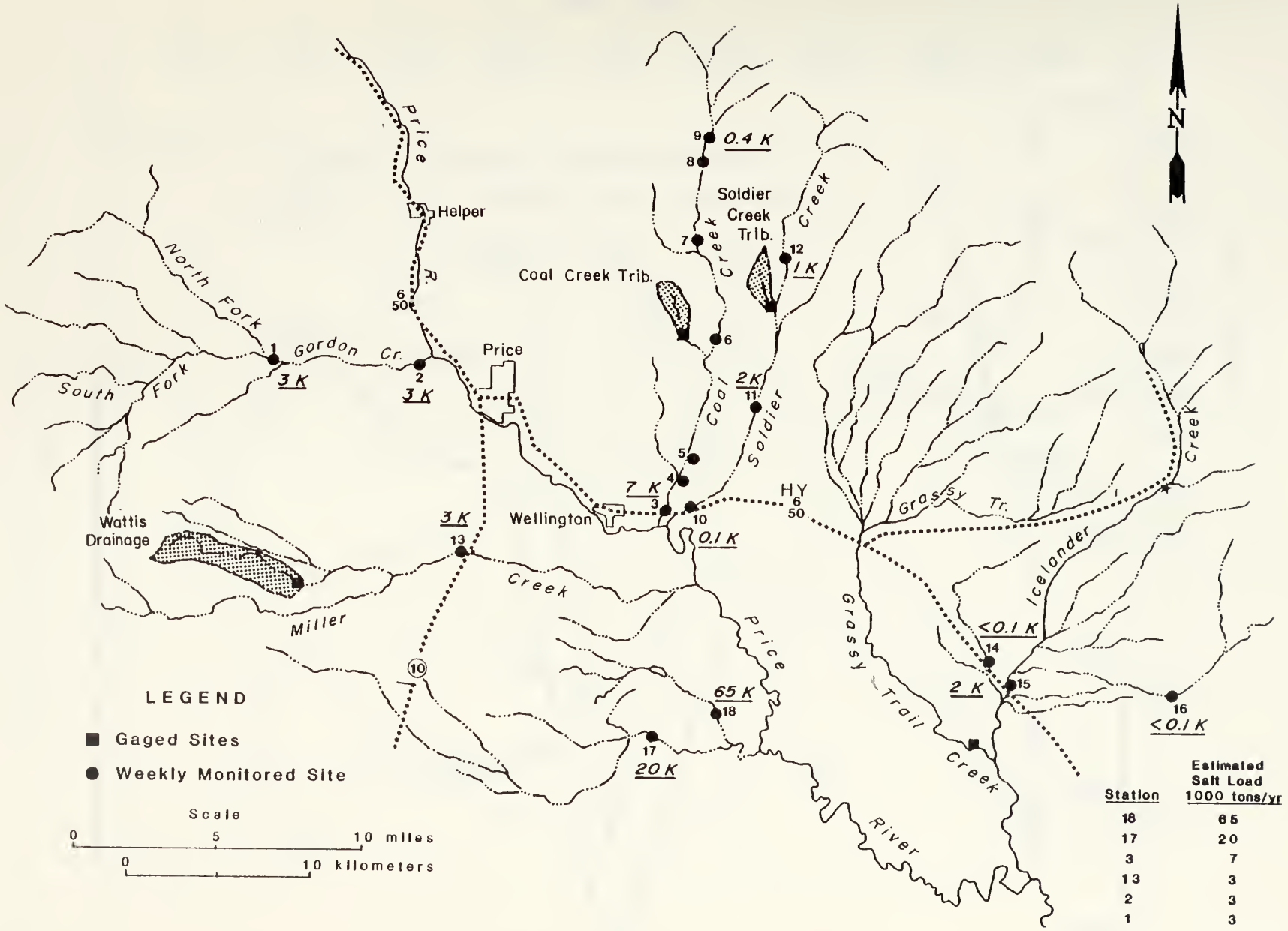
Figure 16 - Monthly Flow Diversion and Moving Averages, Desert Seep Wash.

Figure 17 - Correlation of Estimated Winter Basin Precipitation and Estimated Annual Baseflow volume at 09314280.

Figure 18 - Monthly Flow Diversion at Carbon Canal, Utah.

Figure 19 - Monthly Baseflow Fluctuations Around the Moving Averages, Desert Seep Wash.

Figure 20 - Cross Correlation Between Filtered Flow Diversion at Carbon Canal and Baseflow at Desert Seep Wash.



Station	Estimated Salt Load 1000 tons/yr
18	65
17	20
3	7
13	3
2	3
1	3
15	2
11	2
12	1
10	0.1
14	<0.1
16	<0.1

FIGURE 1.– Estimated Baseflow Salt Load at Selected Stations in the Price River Basin, Utah

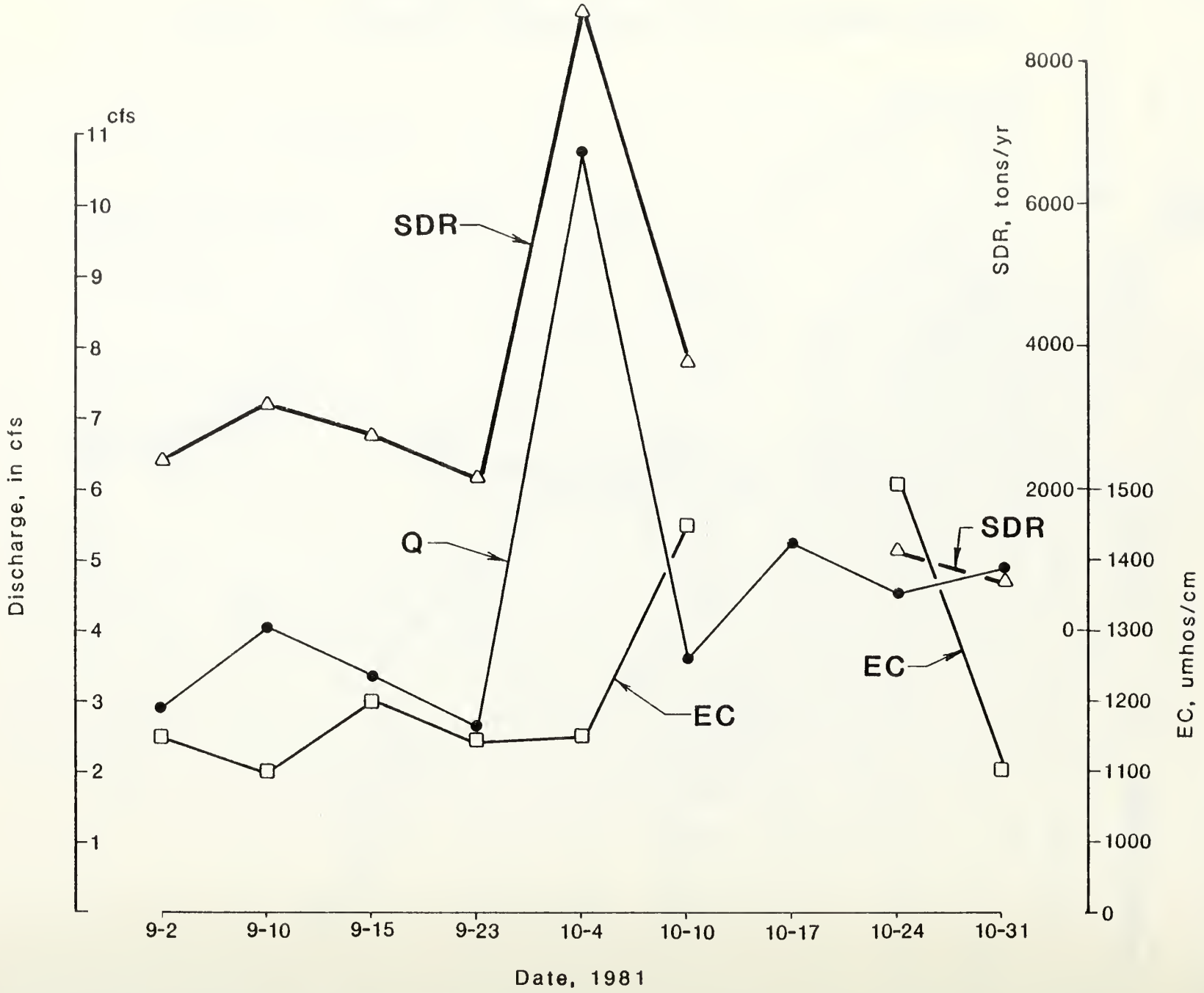
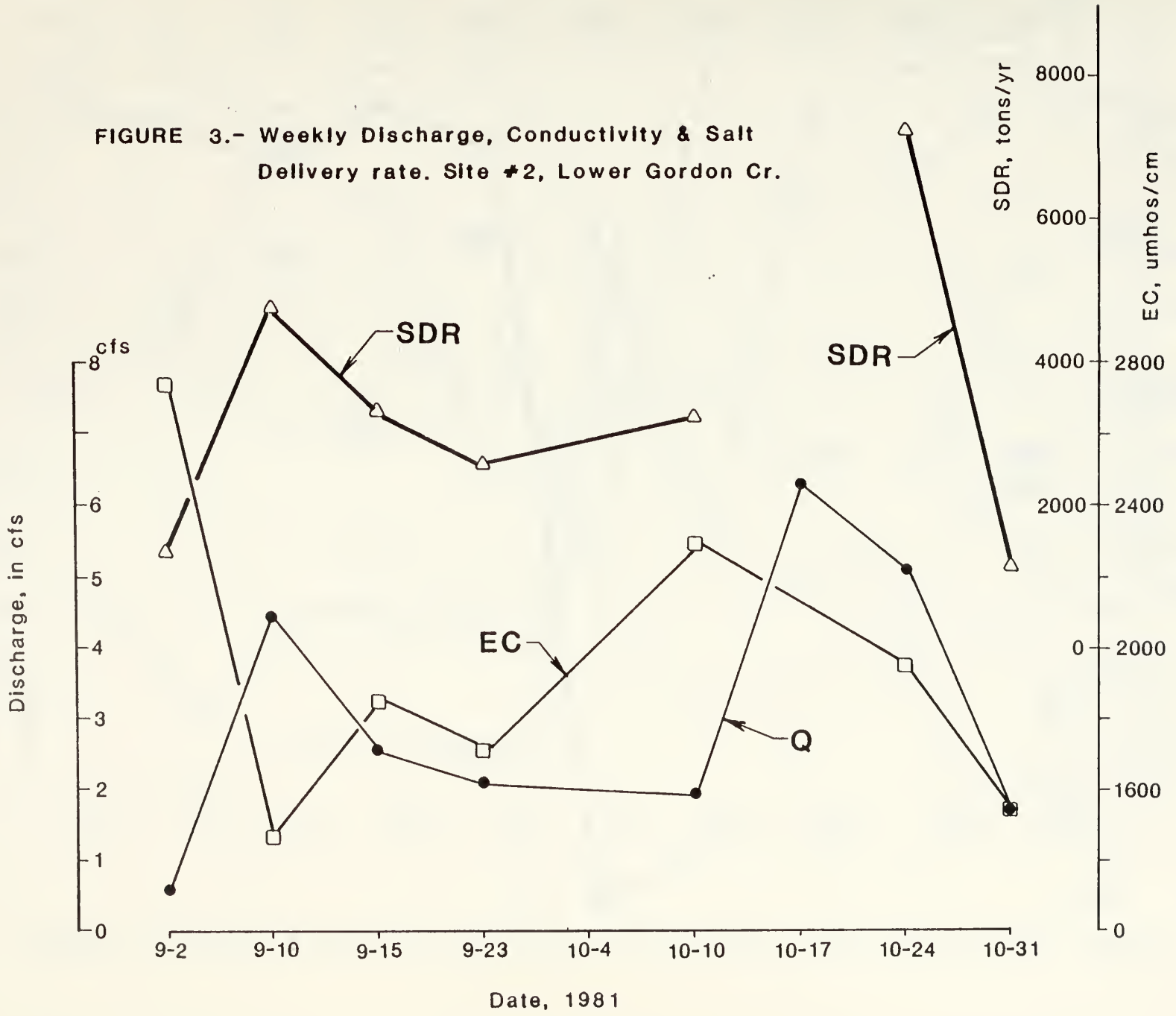


FIGURE 2.- Weekly Discharge, Conductivity & Salt Delivery rate. Site #1, Upper Gordon Cr.

FIGURE 3.- Weekly Discharge, Conductivity & Salt Delivery rate. Site #2, Lower Gordon Cr.



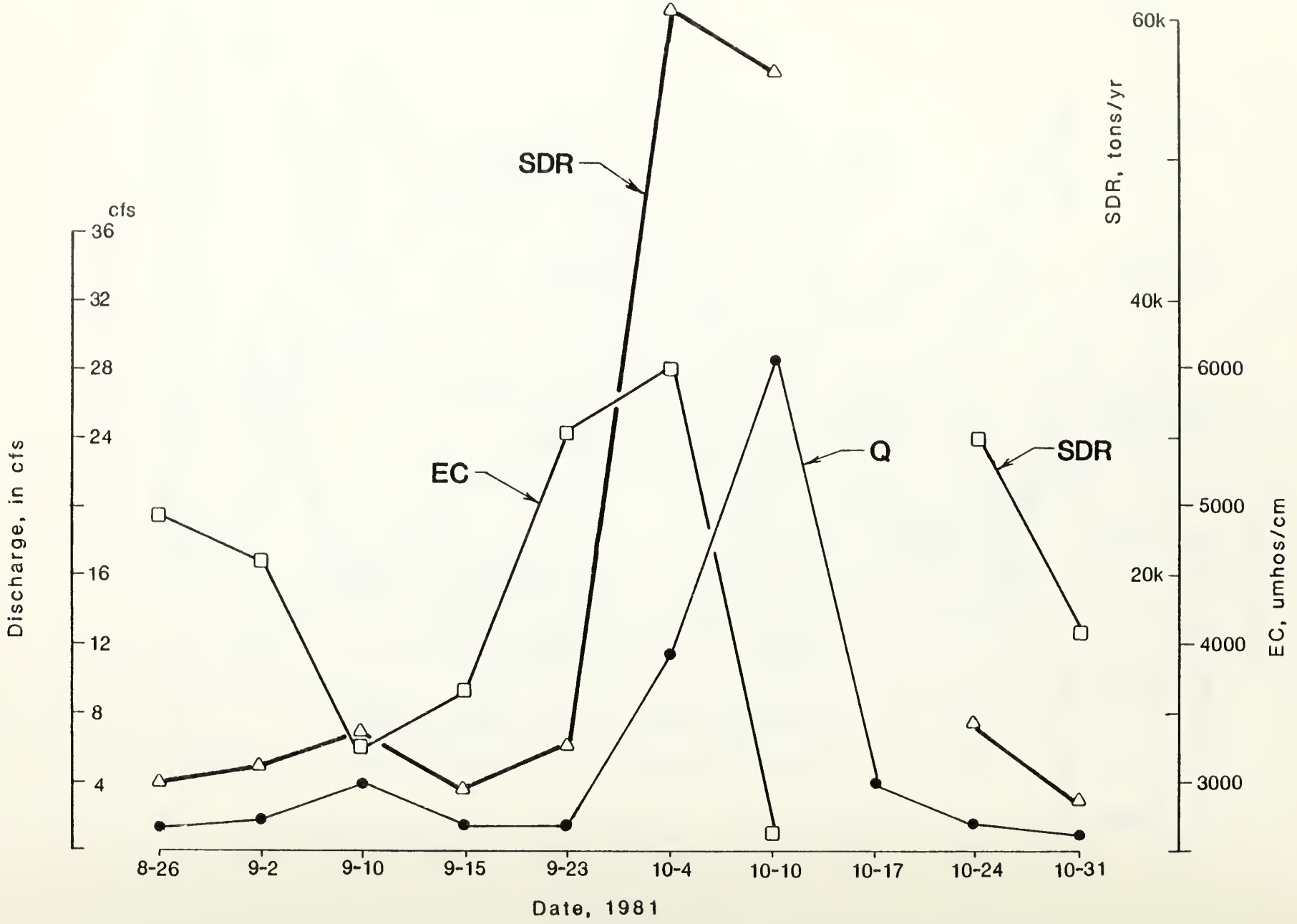


FIGURE 4.- Weekly Discharge, Conductivity & Salt Delivery rate. Site #3 , Coal Cr.

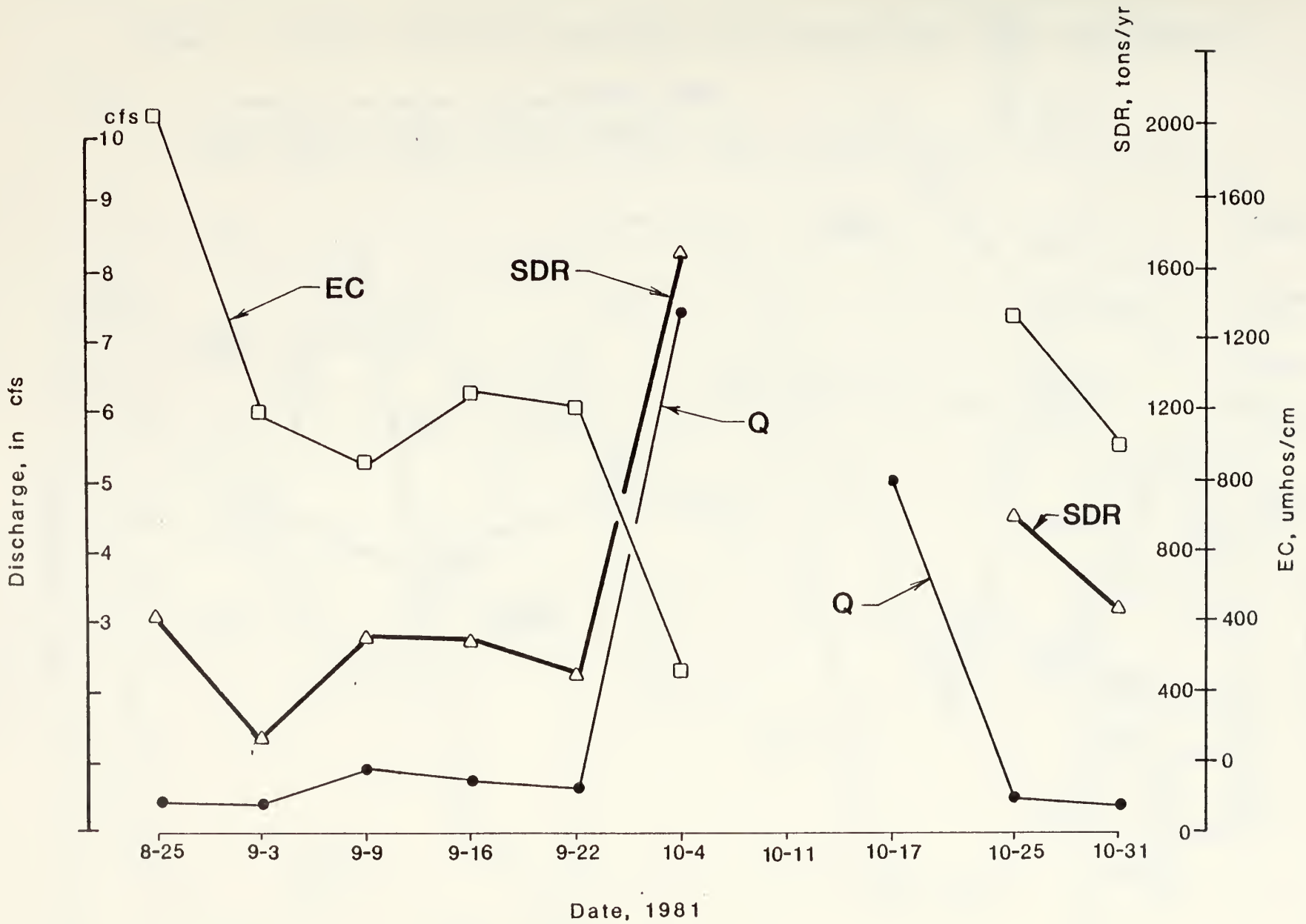


FIGURE 5.- Weekly Discharge, Conductivity & Salt Delivery rate. Site #9, Upper Coal Cr.

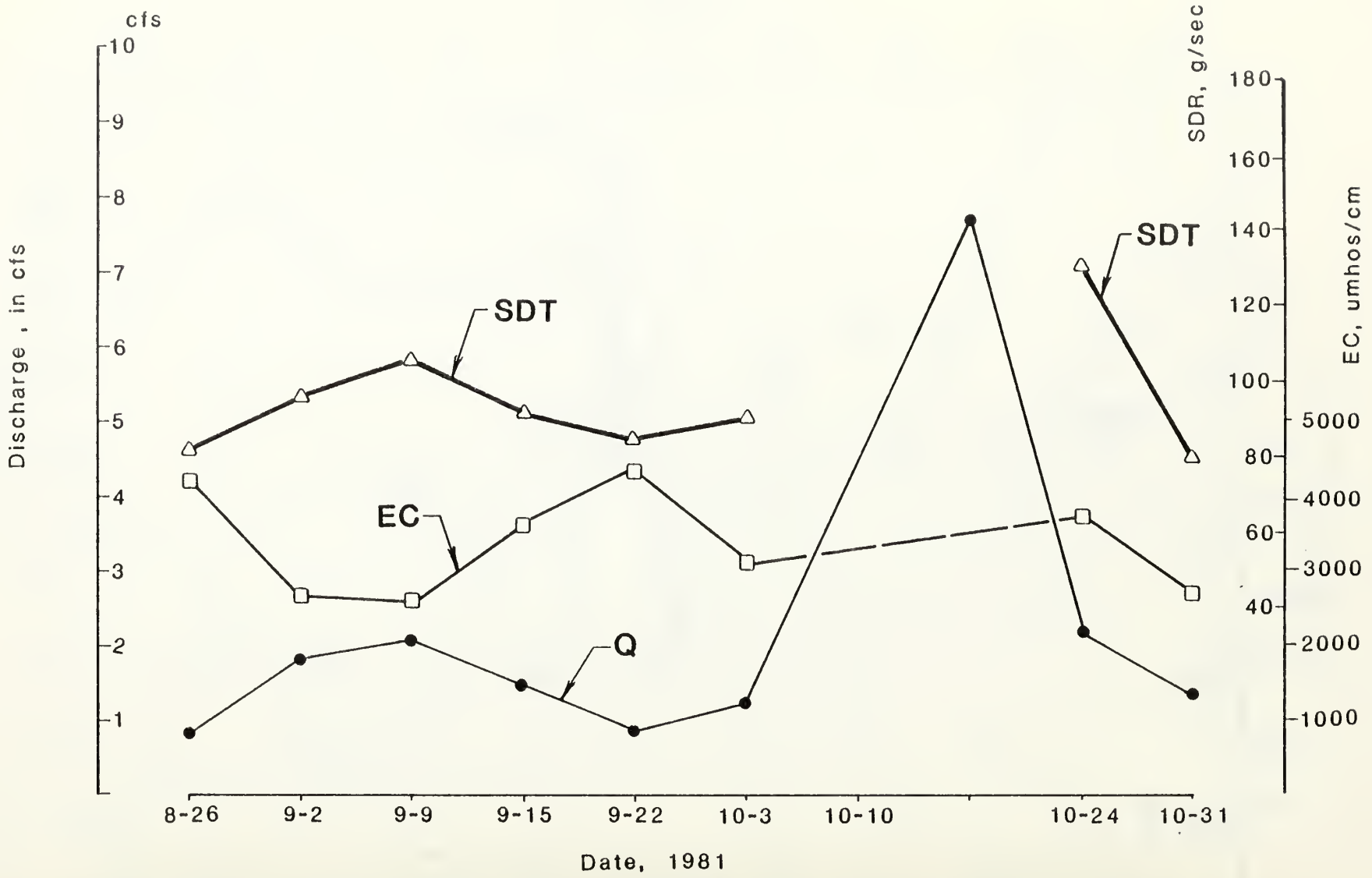


FIGURE 6.- Weekly Discharge, Conductivity & Salt Delivery rate. Site #10, Soldier Cr.

FIGURE 7.- Weekly Discharge, Conductivity & Salt Delivery rate. Site #11, Soldier Cr.

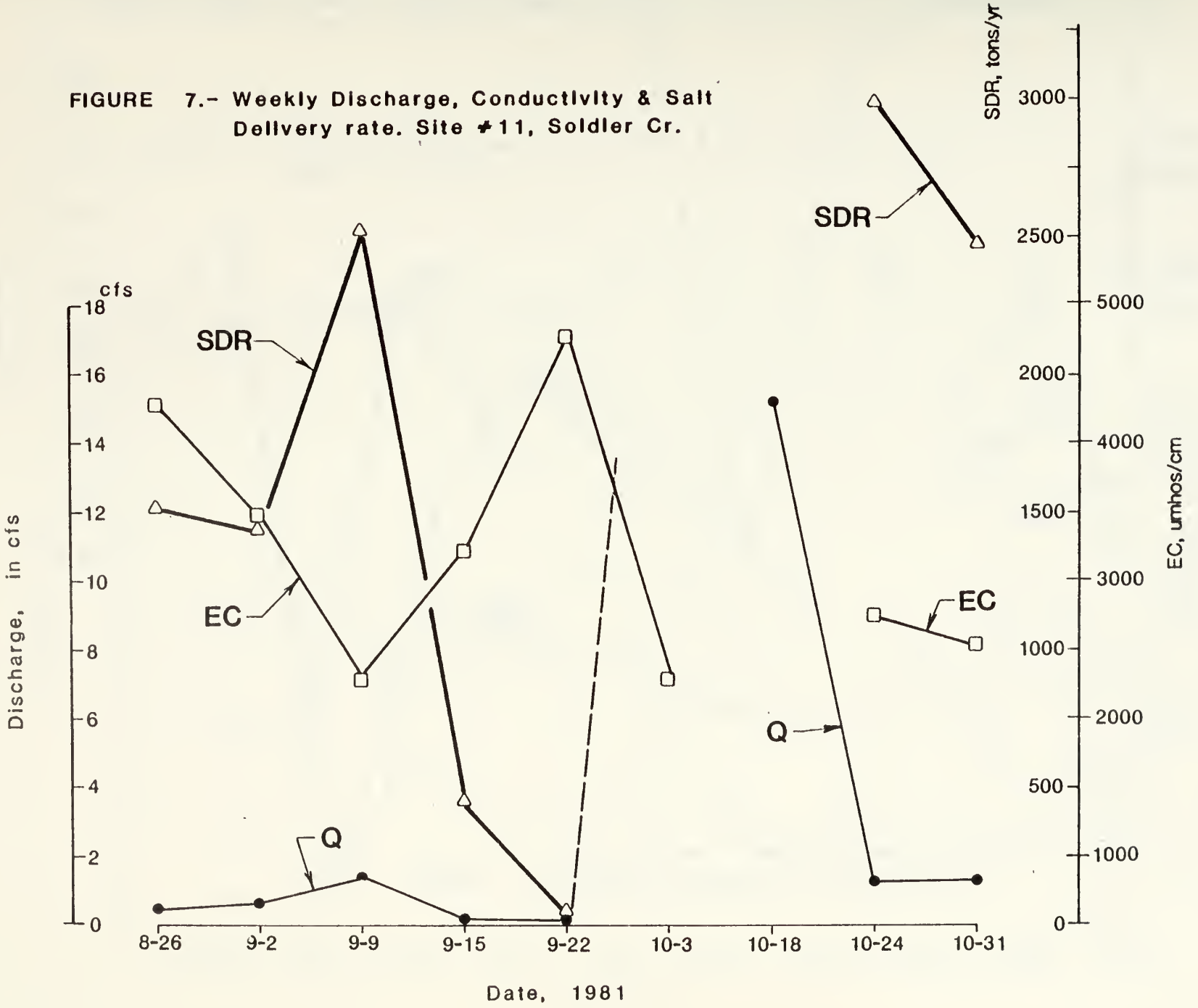


FIGURE 8.- Weekly Discharge, Conductivity & Salt Delivery rate. Site #12, Soldier Cr.

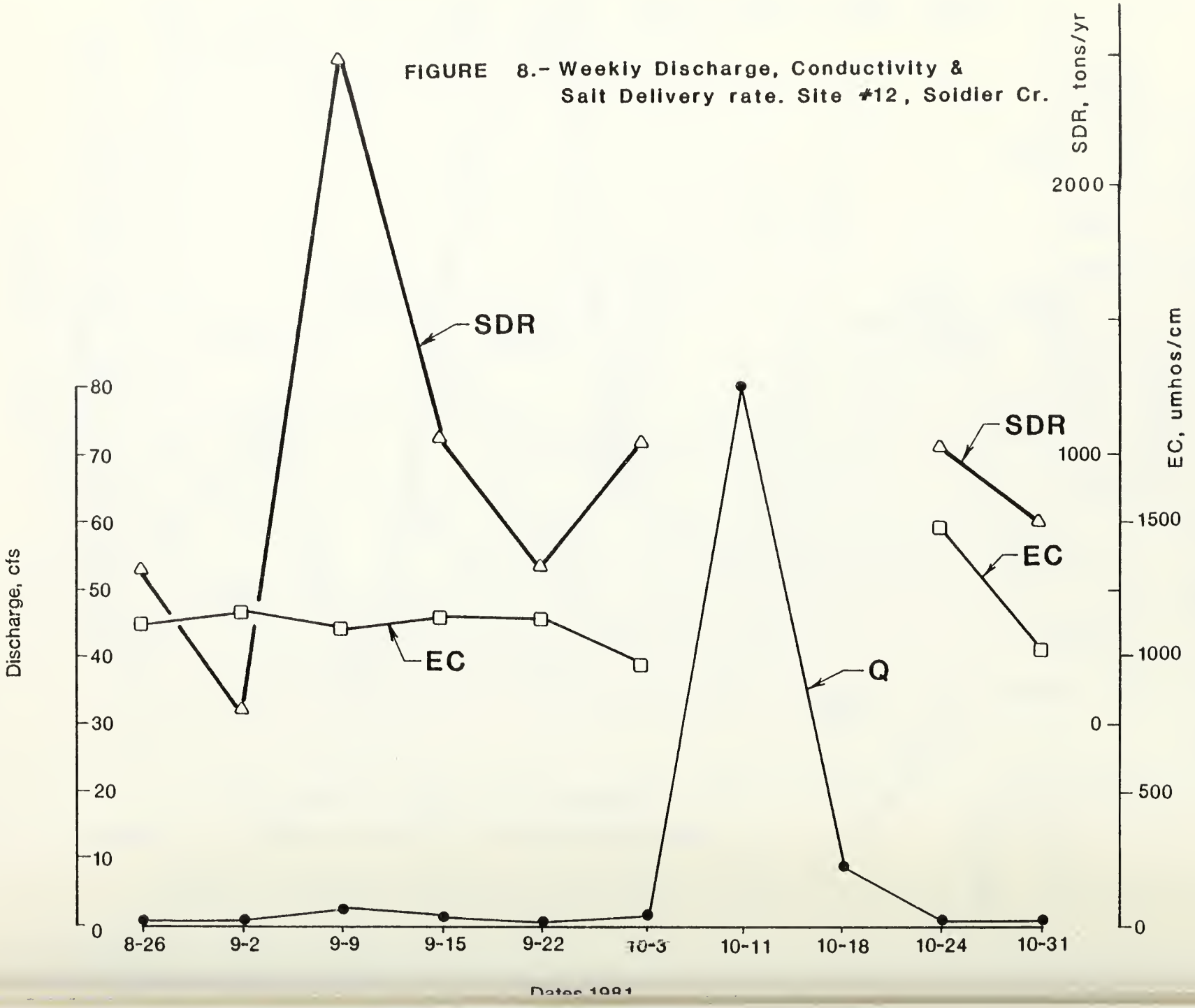
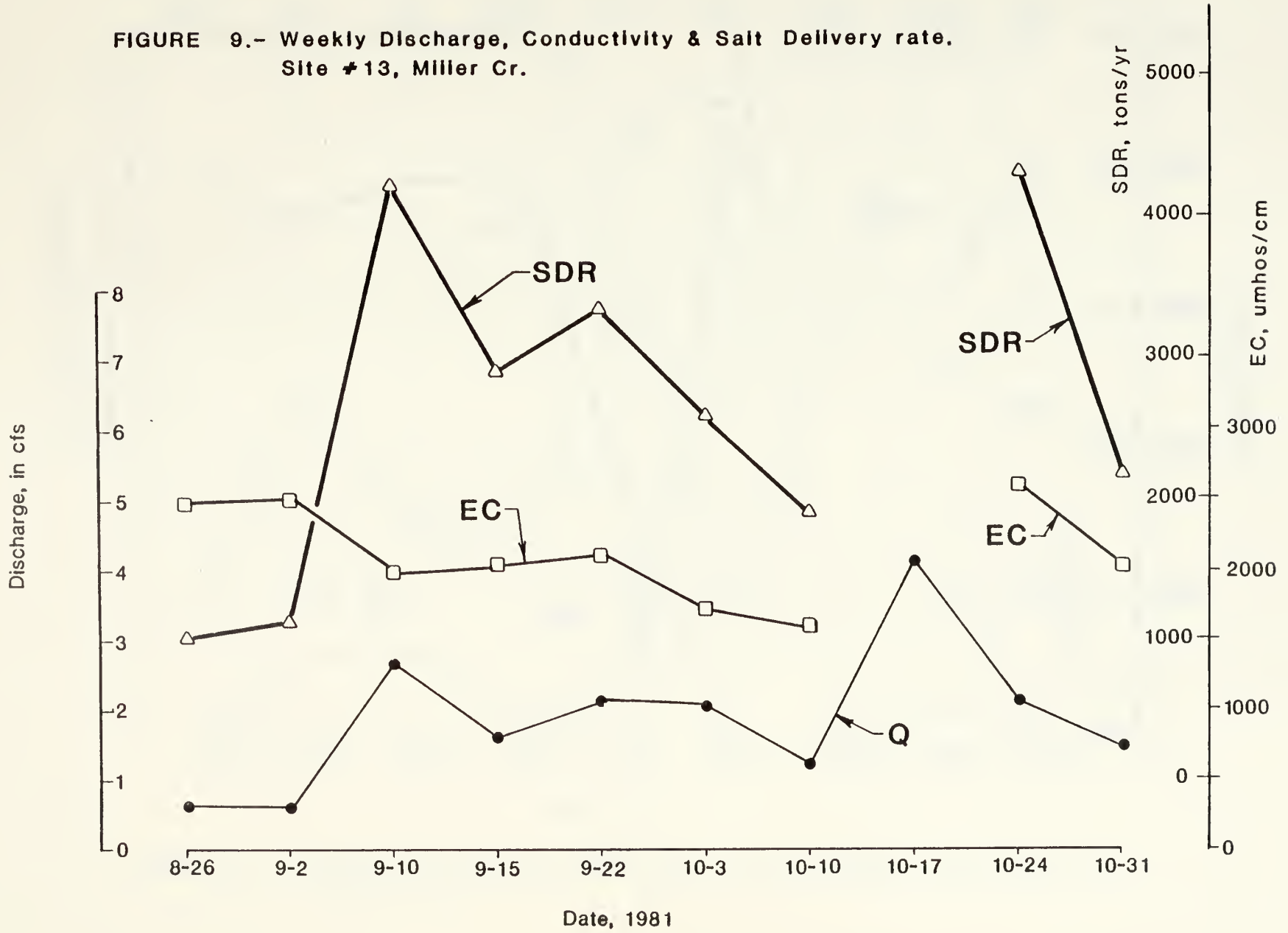


FIGURE 9.- Weekly Discharge, Conductivity & Salt Delivery rate.
Site #13, Miller Cr.



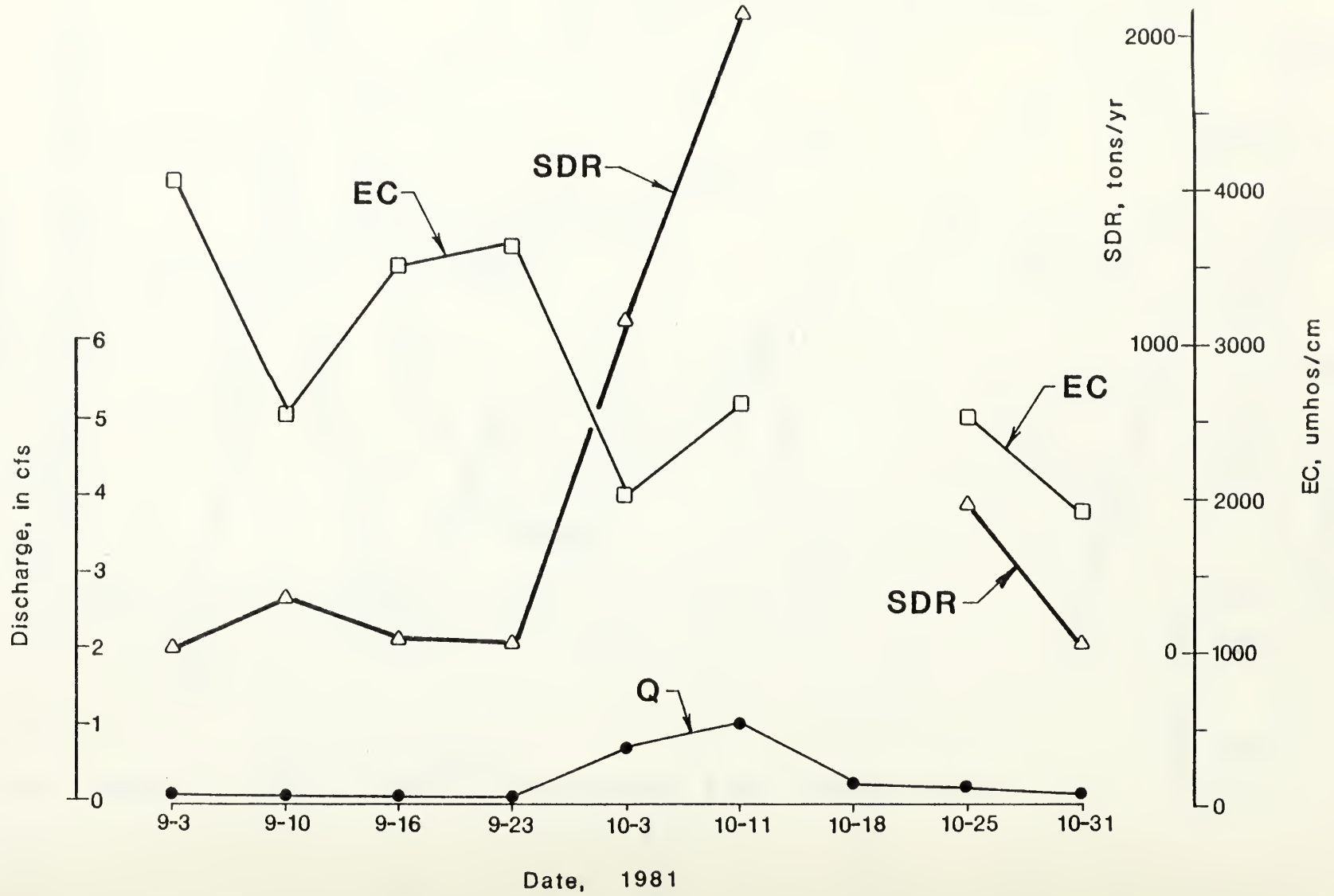


FIGURE 10.- Weekly Discharge, Conductivity & Salt Delivery rate. Site #14, Icelander Cr. trib.

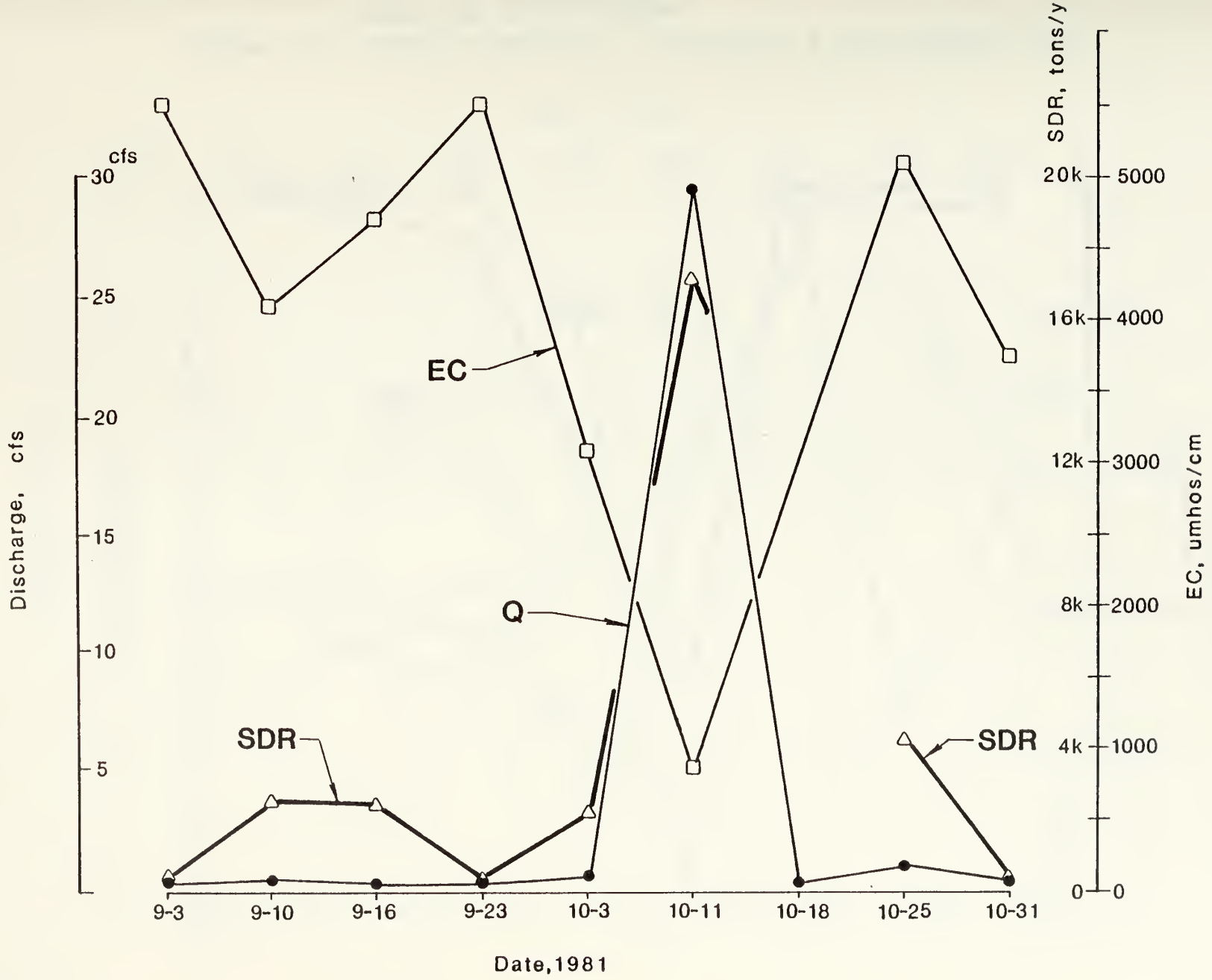


FIGURE 11.- Weekly Discharge, Conductivity & Salt Delivery rate. Site #15, Icelander Cr.

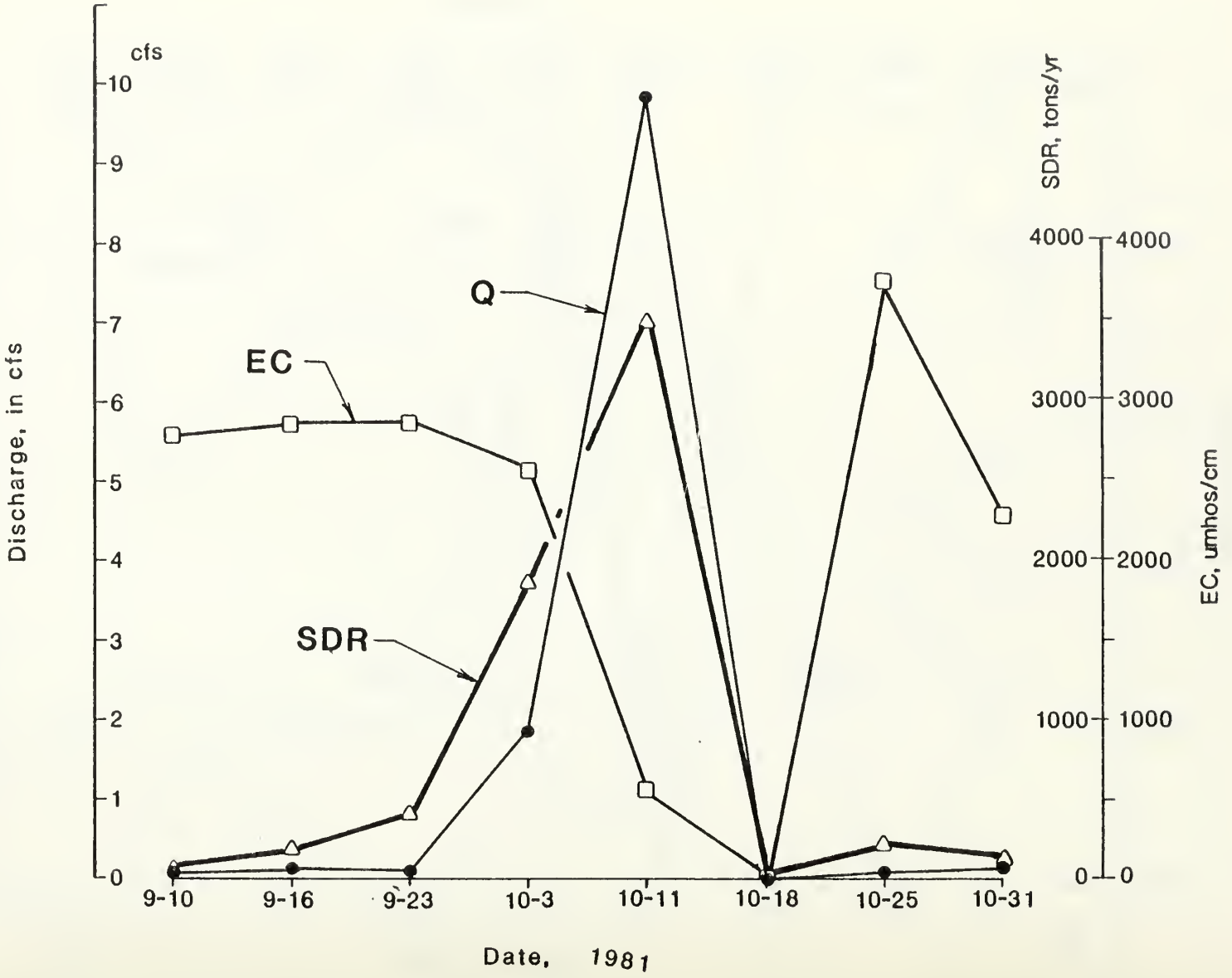


FIGURE 12.- Weekly Discharge, Conductivity & Salt Delivery rate. Site #16, Horse Canyon

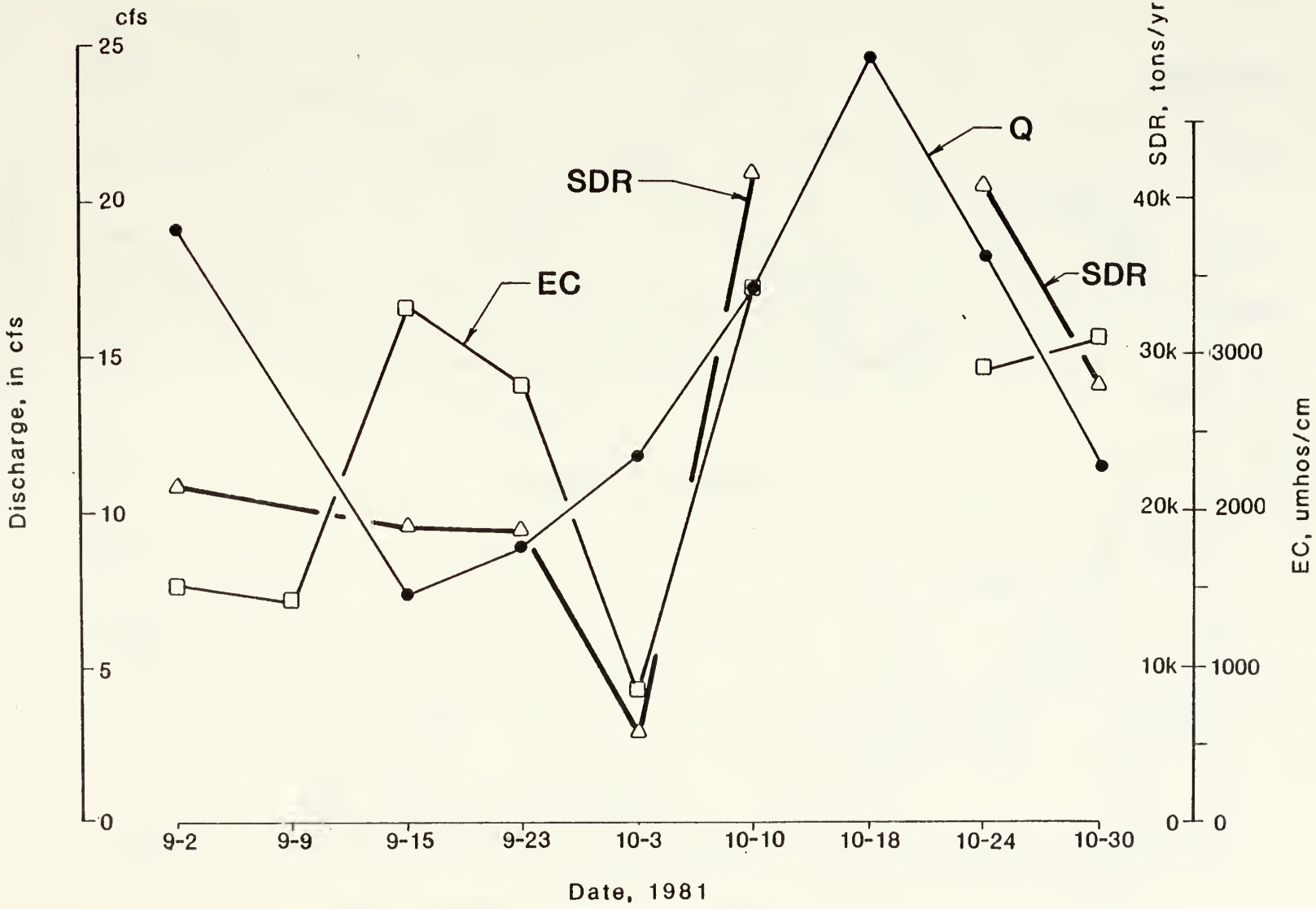
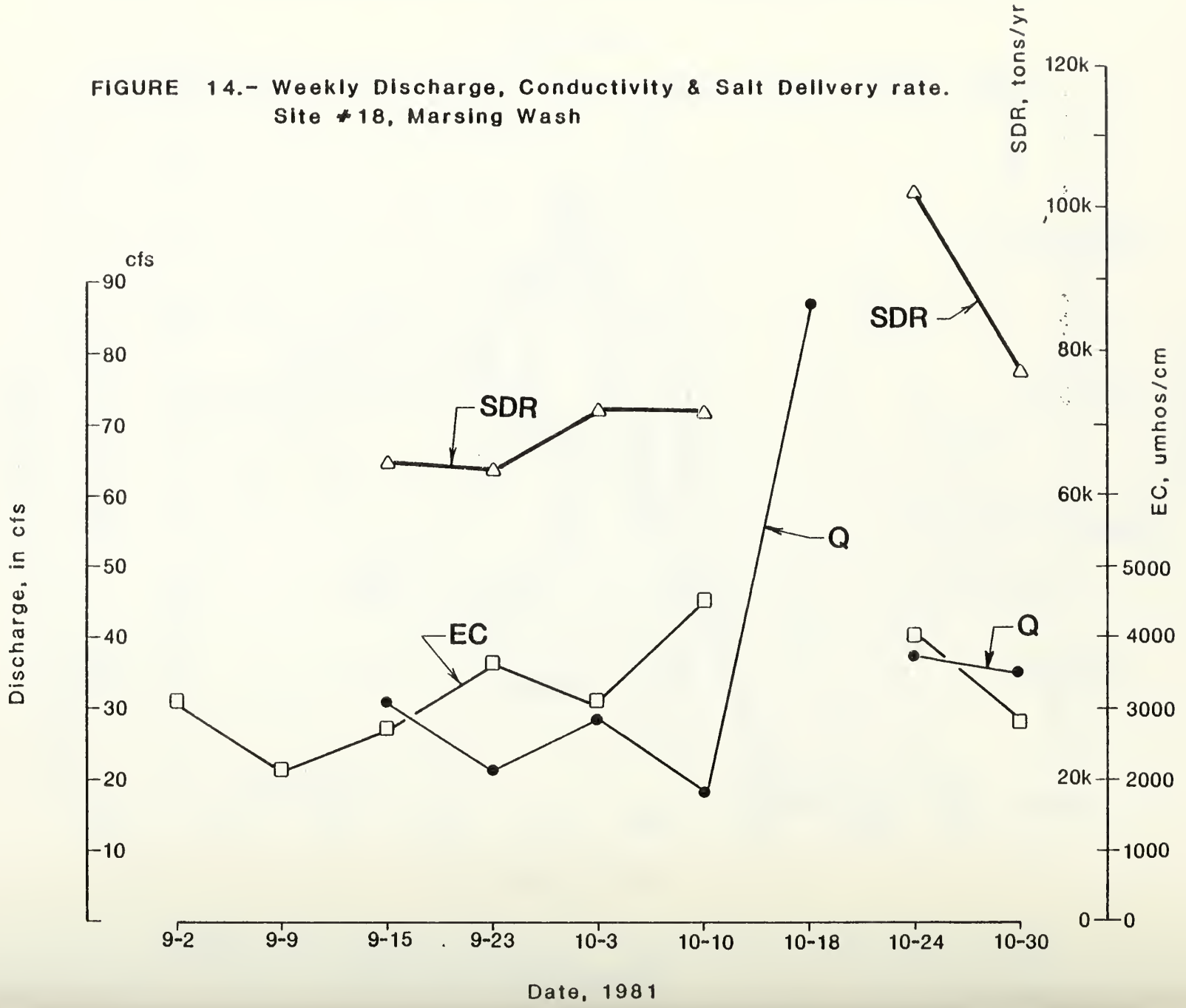


FIGURE 13.- Weekly Discharge, Conductivity & Salt Delivery rate. Site #17, Washboard Wash

FIGURE 14.- Weekly Discharge, Conductivity & Salt Delivery rate.
Site #18, Marsing Wash



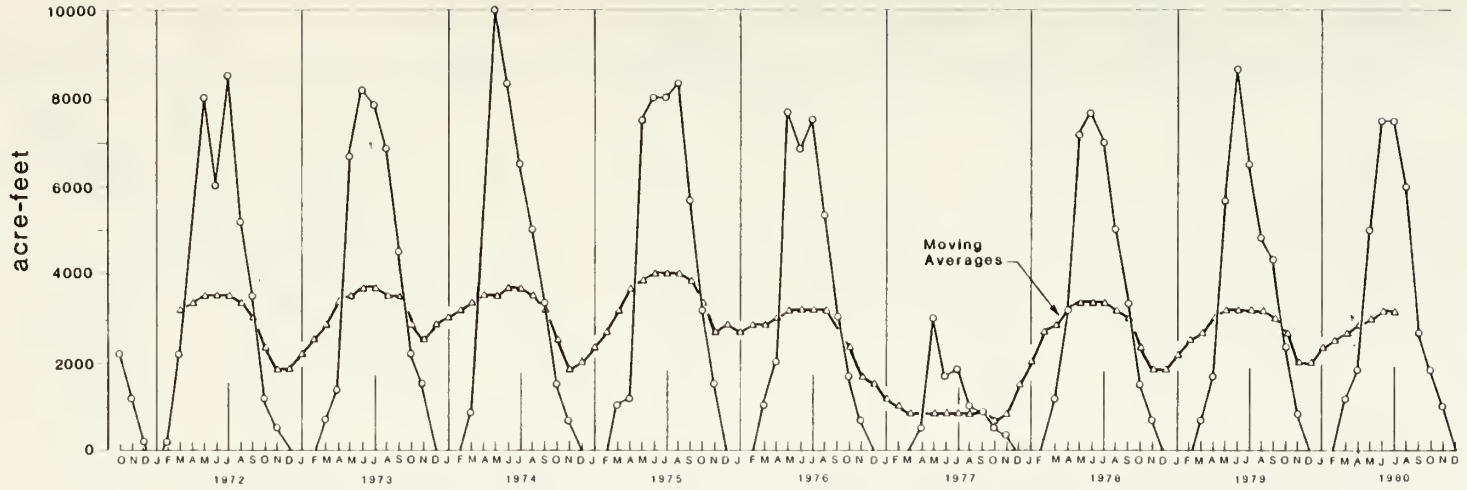


FIGURE 15.–Monthly Flow Diversion and Moving Averages, Carbon Canal

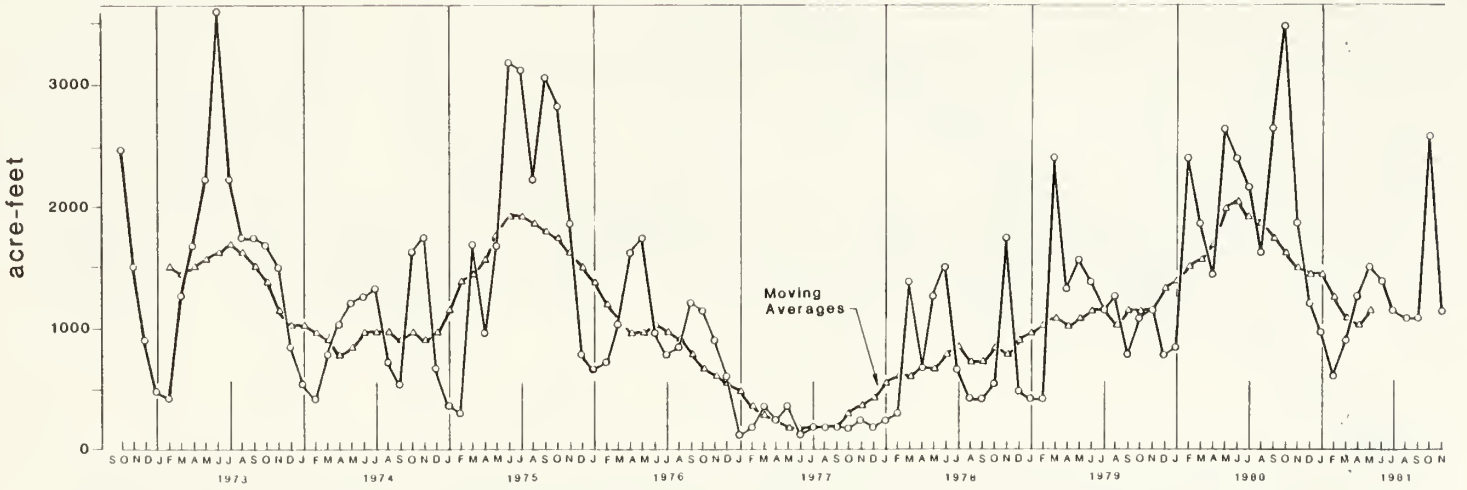


FIGURE 16.–Monthly Baseflow and Moving Averages, Desert Seep Wash

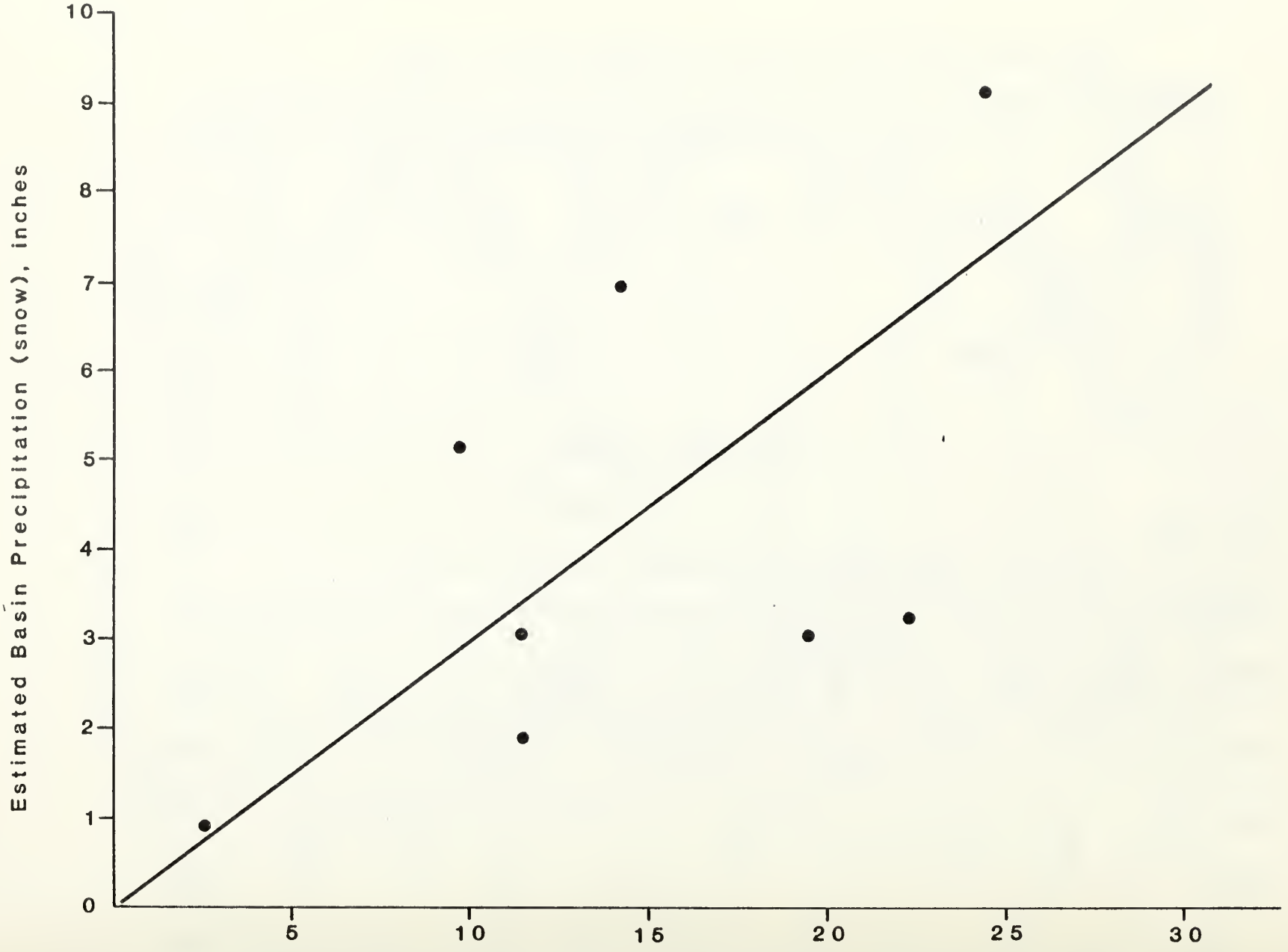


FIGURE 17.- Correlation of Estimated Winter Basin Precipitation and Estimated Annual Baseflow Volume at 09314280

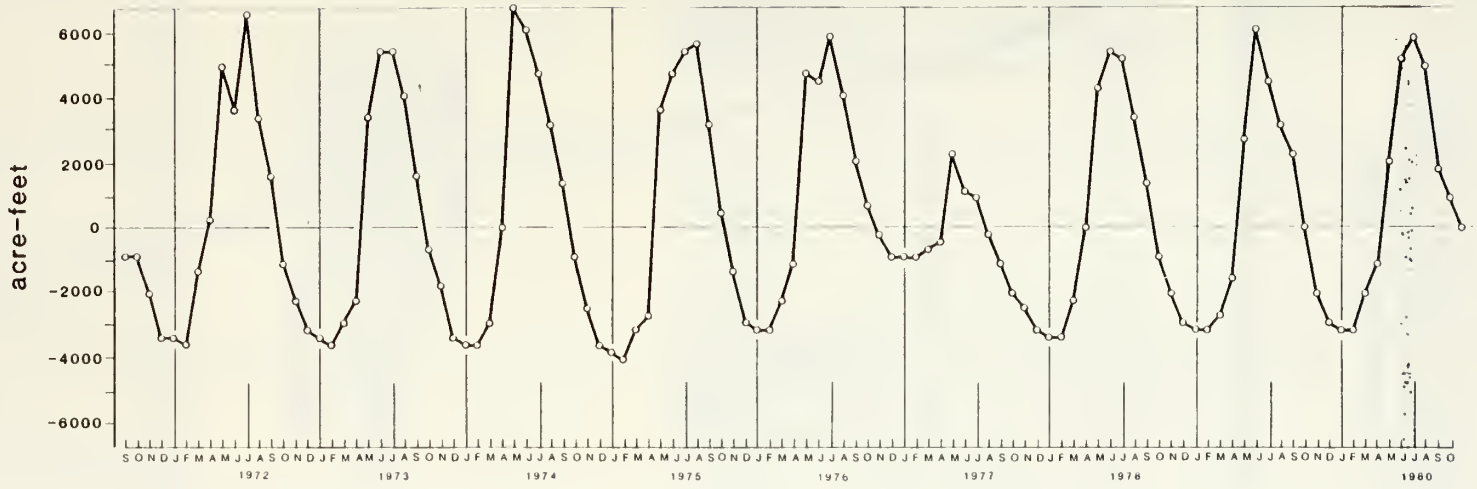


FIGURE 18.-Monthly Flow Diversion at Carbon Canal, Utah

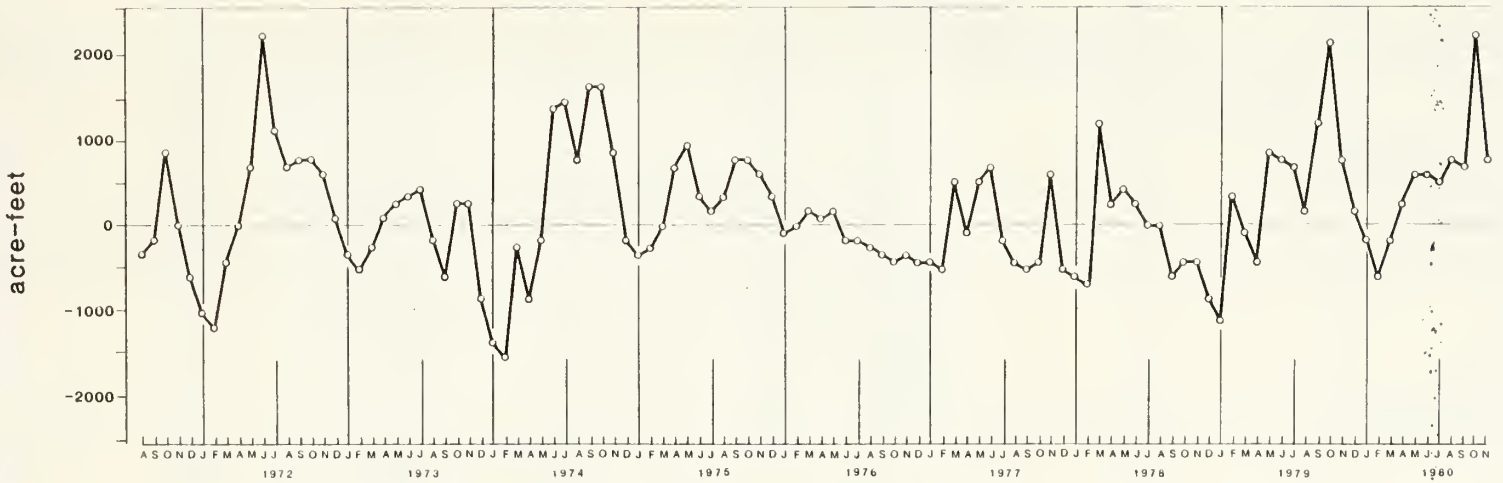


FIGURE 19.-Monthly Baseflow Fluctuations Around the Moving Averages, Desert Seep Wash,

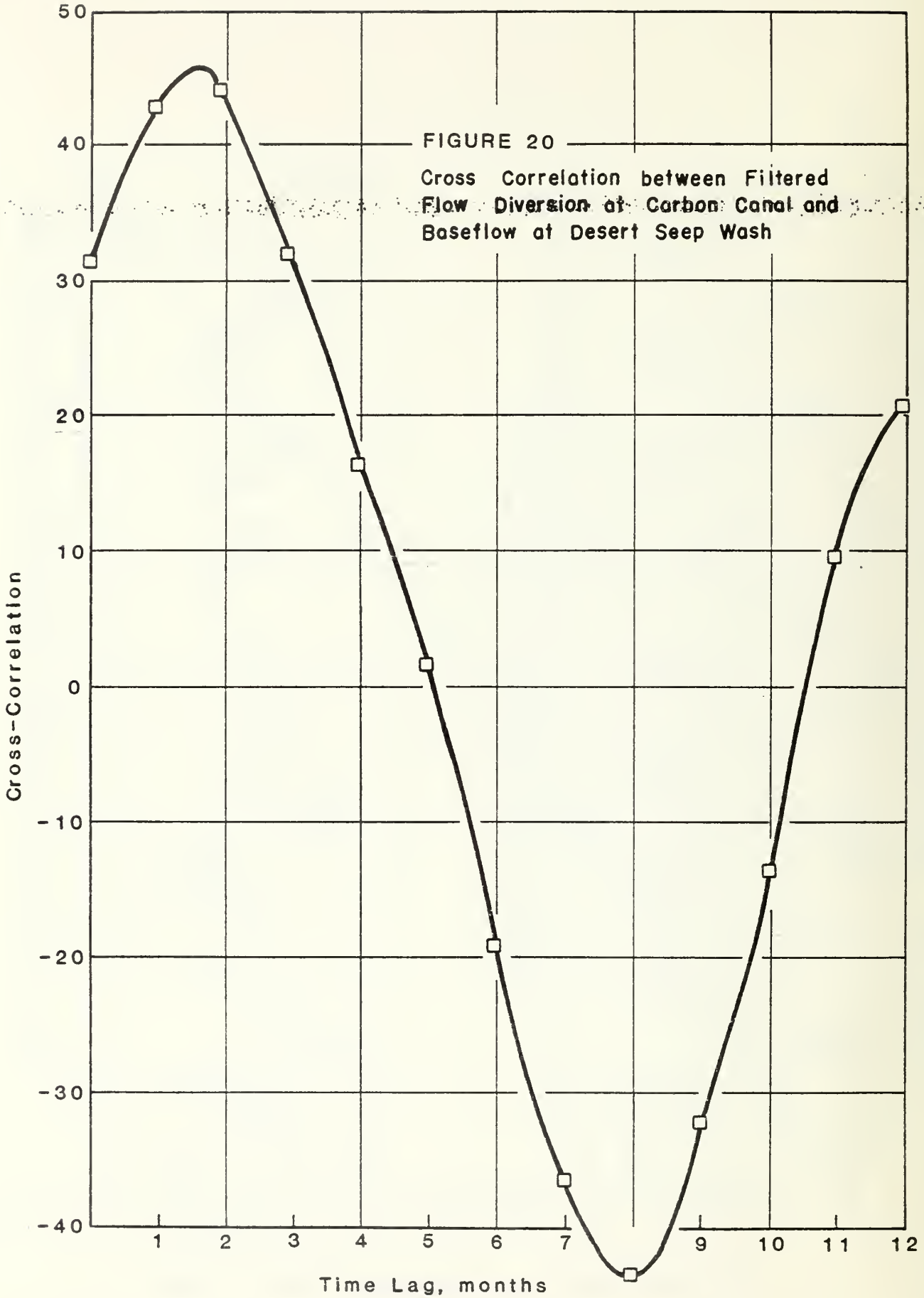


FIGURE 20

Cross Correlation between Filtered Flow Diversion at Carbon Canal and Baseflow at Desert Seep Wash

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